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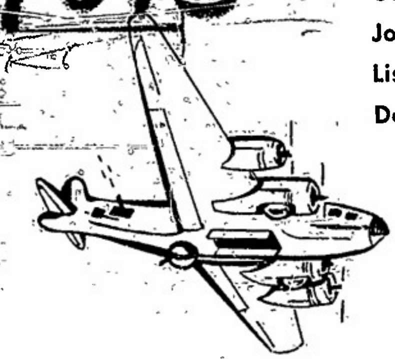
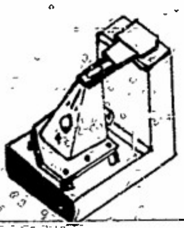


MEMORANDUM
REPORT No. 462

AIRPLANE VULNERABILITY AND OVERALL ARMAMENT EFFECTIVENESS



Herbert K. Weiss
~~Arthur Stein~~

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AIRPLANE VULNERABILITY AND OVERALL ARMAMENT EFFECTIVENESS

MEMORANDUM REPORT No. 462

Herbert K. Weiss
Arthur Stein

ORDNANCE DEPARTMENT
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MD.

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BALLISTIC RESEARCH LABORATORIES
MEMORANDUM REPORT NO. 462

Weiss/Stein/ak
Aberdeen Proving Ground, Md.
21 May 1947

AIRPLANE VULNERABILITY AND OVERALL ARMAMENT EFFECTIVNESS

ABSTRACT

Part I of this report presents the experimental determination of the terminal ballistic effectiveness of the various rounds fired for impact on aircraft targets. Included are the vulnerabilities of both gasoline and kerosene-filled fuel tanks, air-cooled and liquid-cooled reciprocating engines, jet engines, and medium bomber structure, to the various rounds.

Part II of the report estimates overall vulnerability of the P-47 fighter and the B-25 bomber, to fire against the P-47 from the front and below and against the B-25 from the rear and above, both from a range of 500 yards. Vulnerabilities are presented for from one to ten hits on the target.

Part III utilized the terminal ballistic data presented in the first two parts and develops and employs methods for obtaining the overall assessments of armament for a bomber turret and for a fixed gun fighter. In this part are considered the gun and ammunition characteristics, installation weights, distribution of weight between guns and ammunition, the problem of tactics and effectiveness, and the probability of hitting.

ACKNOWLEDGEMENTS

The information contained in this memorandum report represents the result of the coordinated effort of so many people that it is hardly possible to credit each properly. Mention should be particularly made of the continued advice of Dr. T. E. Sterne, Chief, Terminal Ballistic Laboratory. The work of the members of the Arms and Ammunition Division, Proof and Development Services, of Aberdeen Proving Ground, who carried out the firings with their multitudinous associated details, resulted in the basic data on which the analysis of the present report are based.

The painstaking and detailed assessments of damage made by the assessors of the Army and Navy Air Forces are vital to the program and the usefulness of the results depends directly upon the knowledge, training and skill which these men brought to their task.

The lengthy and complex task of reducing the firing records and the assessments contained in them to the probabilities tabulated in this report was carried out by members of the Weapons Effectiveness Branch of the Terminal Ballistic Laboratory, including Miss Mary Gene Torsch, Mr. Norman McLeod, Miss Charlotte Garretson, Mr. Harry Kostiak, Mr. Andrew Todero, Mrs. Shirley Kafer, Miss Bettye Taylor, and Mr. Robert Miller. The drawings and charts were prepared by Miss Adelaide Armstrong.

Lt. Col. F. S. Allen, AAF, Air Materiel Command Liaison Officer has been especially helpful; both in comments on the program, and in aiding the authors to obtain various types of related information which contribute to the study. The importance of having this material quickly available when required cannot be overemphasized.

INTRODUCTION

The so-called "Optimum Caliber Program" was initiated under the authority of File 00 4.00.112/ 21424 (c) on 23 July 1945. Actual firings against aircraft on the ground have been under way for over a year. In this time 287 aircraft of various types have been completely expended and 5 aircraft have been partly expended. Since a single twin-engined aircraft contributes two engines to the engine phase of the program, fuel cells to the fuel ignition phase, and a structure to the structures phase, it will be appreciated that a tremendous amount of detailed information is available regarding damage to all of the components of an airplane.

Insofar as future aircraft are composed of similar structure, fuel cells, or powered by similar engines, the information obtained in the present tests can be applied directly to the corresponding components of other aircraft, with due correction for presented areas and physical arrangement. For slight structural changes, the vulnerability of future aircraft can be estimated. When certain components only are radically different (such as advanced designs of jet engines as opposed to the obsolescent I-16 jet engines available for these firings) some estimation is possible, but in any event, only the new component need be subjected to damage tests for the estimation of the overall vulnerability of the new aircraft.

The purpose of the Optimum Caliber Program is not only to determine the probability that a single round of present ammunition striking an airplane will cause damage in the various possible categories, but also to assess the overall effectiveness of complete armament installations, with the object of indicating the answer to the whole problem,-what armament should be carried by aircraft to meet various tactical situations.

The present report therefore represents a progress report on the two complementary portions of the Optimum Caliber Program. In the first section of this report the results of the actual firings against aircraft are reported, and the conditional probabilities of damage resulting from a hit are determined from the experimental information. In some cases confidence limits are presented to indicate uncertainties in the information. Methods are given for combining the component probabilities to give the overall probabilities that the airplane will be destroyed if it receives any arbitrary number of hits. The second portion of the report is concerned with the events that lead up to the impact of rounds on the airplane. Tactics, fire control, exterior ballistics, armament weight, rate of fire, and dispersion, are a few of the variables which enter this discussion. Comparisons of armament are made for simple tactical situations, limited by the range of field data available at the time of writing.

Methods of analysis as well as the values obtained from the experimental firings are subject to modification as the study progresses and more information is made available. The indications of the present report should be considered therefore, not as a final evaluation of the comparative performance of the weapons involved, but as an indication of the work being done, and as a tentative preview of the sort of results which it is hoped to attain as the program progresses.

Part I

EXPERIMENTAL RESULTS

The present report is concerned with the analysis of impact firings on aircraft carried out at Aberdeen Proving Ground, through December 1946. A prior report[1] presented analysis of the firings up to May 1946. A detailed description of the methods of testing and damage assessment employed in the Optimum Caliber Program is contained in the first report. Only such information as is required for the understanding of the data presented in the succeeding paragraphs will be noted in the present report.

STATUS OF THE PROGRAM

The major portion of the firings covered by this report were conducted against B-25 twin-engined medium bombers at a range of 500 yards. A number of tests were also made against liquid-cooled engines in the P-38 fighter, I-16 turbo-jet engines in the P-59 fighter, gasoline and kerosene-filled fuel tanks of the P-38 and kerosene-filled tanks in the P-59.

Appendix A lists the number of firings in each phase with the various calibers and type of ammunition employed. While most of the firings were carried out at a ground range of 500 yards, it must be remembered that ranges at which the same striking velocity would be obtained in aerial combat vary with the relative velocities of the aircraft and with altitude. Table I presents the chief allocations of aircraft to future firings as now contemplated. In addition to this program, certain supplementary firings are anticipated. The choice of other ranges for supplementary firings will be made to give striking velocities obtained in those tactical situations in which it is desired to evaluate the effectiveness of the weapons.

For example, rounds fired from aircraft approaching head on at high altitude may have much higher striking velocities than those obtained in ground firings at 500 yards. It is therefore anticipated that supplementary firings will be arranged under conditions providing these high striking velocities. The extent and precise ranges for these firings are dependent upon the results to be obtained in the current series of firings, and are not yet determined. It is expected that the number of aircraft involved will be relatively small compared to those fired at 500 and 1000 yards. Firings at 1000 yards are now in progress and it is expected that analysis of these firings will form the basis of a later report.

BASIS FOR ASSESSMENTS OF DAMAGE

A detailed description of the method of aircraft damage assessment used in the Optimum Caliber Program is given in BRL Memorandum Report 437. The following brief summary pertains chiefly to the airplanes reported on in the present report

1. Optimum Caliber Program, Ballistic Research Laboratories Memorandum Report No. 437, by Arthur Stein, 1 July 1946.

TABLE I

Future Requirements, Optimum Caliber Program, 14 February 1947

Phase	Range 500 yards	Range 1000 yards	Total
A. Impact			
1. B-25 Engines	73	60	133 Engines
2. P-59 Jet Units	14	0	14 Engines
3. P-47 Engines	117	40	157 Engines
4. (a) B-25 Structures	42	39	81 Planes*
(b) B-25 with Remaining Energy Plates	66	0	66 Planes*
5. P-47 Structures	75	0	75 Planes*
6. P-38 Fuel Tanks			
(a) Gasoline Filled	24	32	56 Planes
(b) Kerosene Filled with Armor Protection	23	31	54 Planes
(c) Gasoline Filled	21	0	21 Planes
(d) Kerosene Filled	23	0	23 Planes
7. P-59 Fuel Tanks			
(a) Kerosene Filled	9	0	9 Planes
B. Air-Burst			
1. 75mm vs. B-25 Engines, Structures, Fuel Tanks			10 Planes
2. 105mm vs. B-25 Engines, Structure, Fuel Tanks			24 Planes
C. Blast			
1. P-59 Jet Units			6 Units
D. Controlled Fragmentation			
1. B-25 Engines, Structure, Fuel Tanks			150 Planes
2. P-59 Jet Units and Fuel Tanks			12 Units (6 Planes)
3. F6F, B17, B29			Undetermined

* Firing to be conducted against possible vulnerable areas rather than entire plane.

Assessments consist of both a qualitative description and numerical assessment of the damage caused by each round impacting on the target. Damage is described with sufficient thoroughness so that interested agencies may make wider use of the results than would be permitted by numerical assessments alone. In general, description of damage includes the location of the point of impact, of the point of functioning if an H.E. or incendiary projectile, of significant perforations, of effect of armor, of fire or other types of damage and of points of exit. Description of the type of functioning of H.E. or incendiary is made. The extent of fuel tank leakage, slowing or sputtering of an engine, loosening or jamming of control surfaces, blast effect on the particular type of structure and similar pertinent observations are recorded. In tests on the running engines, the cylinder head temperatures, manifold pressures and R.P.M. are all recorded. Small fragment holes which are not considered damaging are usually recorded in number only with lower and upper limit of size. Also in the description of damage are included such qualifying statements as make the numerical assessments more meaningful; such as special assumptions of flight conditions not previously considered. These assessments are then issued in the form of Aberdeen Proving Ground Firing Records.

Assessments of aircraft damage often will vary according to the tactical situation. For this reason, some basic assumptions must be made to which the assessments apply. The following assumptions, compiled from combat reports and assessors' conferences, are made with regard to the B-25 medium bomber.

1. The aircraft is in level flight, at an altitude of 10,000 ft., with a speed of 200 m.p.h. IAS, on a solo mission. It is on its bomb run and is 2 1/2 minutes from the point of release of bombs. No evasive action is necessary.
2. The target is an area of 500 x 1000 feet.
3. The bombsight is pre-set for 200 m.p.h. IAS and any deviation from that speed at the time of release of bombs would effect which is known as "C" damage.
4. Each engine has a spring-loaded throttle on the carburetor that will maintain 30" Hg manifold pressure in event the throttle cables are severed.
5. The aircraft flies to the target on fuel in the auxiliary wing cells and has all four main fuel cells full for the return to "base".
   (a) On twin-engine operation 125 gallons per hour are consumed.
   (b) On single-engine operation 180 gallons per hour are consumed.
6. Both pilots are as competent as possible, know all emergency procedures, and each member of the crew has a working knowledge of every other man's assignment.
7. The aircraft is equipped with dual surface-control cables throughout the fuselage.
8. The "base" landing area is a steel mat 100 feet wide and 6000 feet long.
9. The mission is to drop 12 100-lb G.P. bombs on the target.

Definitions of Numerical Assessments

Damage is assessed in the following four categories:

"A" Damage is the probability that the aircraft will start to fall or go out of control within a period of five minutes from the time it is hit. The letter "K" in the A column denotes a crash immediately without any reasonable doubt. The letter "KK" in the A column denotes a crash immediately without any reasonable doubt and in addition denotes complete defeat of the attack. Such a designation will indicate for example that a Kamikaze attack upon a ship will be defeated. A kill of a fighter pilot would be a "K" kill; an explosion disintegrating the plane would be a "KK" kill.

"B" Damage is the probability that the plane fails to return to base as a result of the assessed damage, the base being two hours away. This probability includes the five minute period immediately after the burst as well as the time required to return to base after the five minutes have elapsed. Thus "B" damage assessments will always be equal to or larger numerically than "A" damage but will never exceed 100%. The sum of the "A" and "B" damage may exceed 100% and an assessment of 100 "A" implies an assessment also of 100 B.

"C" Damage is the probability that the particular attack will not be completed. It is possible to have "C" damage although no "A" or "B" damage exists. Thus, damage to guns, bomb release mechanism, controls whose loss would interfere with the prosecution of the attack, or personnel involved in the attack, would

be classed as "C" damage. An immediate kill, KK, implies 100 "C" damage. In assessing "C" damage, or in fact any category of damage, it is assumed that the pilot will remain with the plane and try to prosecute the attack, even though "bailing out" is feasible. The assumption that the attack is 2 1/2 minutes away is also an important one in evaluating "C" damage. "C" damage will be treated in a later report.

"E" Damage is the probability that the plane will be structurally damaged while landing. ("D" damage, which pertained to man hours required for repair of damage has been omitted and is not assessed.) "E" damage will be treated in a later report.

Compound Damage. Any round fired into an undamaged area or component may be given a single shot assessment. A round fired into a previously damaged area or component will result in compound damage, and a "compound assessment" is given to the combination of hits in the area. The compound assessments are used in evaluating the conditional probability for obtaining such damage in actual combat.

Cumulative Damage. Cumulative damage assessments are given for damage to the entire plane in the phase being conducted. Thus whereas two hits on the same fuel cell may cause both compound and cumulative damage, two hits on tanks on opposite side of the plane may be assessed singly and also cumulatively where the resulting damage to the plane is greater than would be expected from the single shot assessments alone.

Assessors and Proof Directors

The validity of the terminal ballistic data obtained from firings against aircraft depends to a great extent on the technical knowledge and experience of assessors and proof directors. The men assigned to this program have been careful and conscientious in their work. They have each contributed the independent judgment required and have not hesitated to go far afield for sources of information which would aid them in improving damage assessments. Acknowledgement is also due to the assistant assessors and crew chiefs. Their job calls for infinite patience and they have effectively increased the amount of data obtained from any one plane. In certain instances they repaired over 20 fuel lines in damaged jet engines to add one additional round to the scanty data for such engines. The assessors, assistant assessors, crew chiefs and proof directors connected with the program from July 1946 to December 1946 are listed below in Table 2.

TABLE 2

Assessors and Proof Directors

Assessors

Name	Speciality	Organization	
Col. M. Wilson	Engines	Powerplant Lab.	A.M.C. Wright Fld., Ohio
Mr. J. Medici	Structures	Aircraft Lab.	Wright Fld., Ohio
Mr. R. McKinnie	Blast	Aircraft Lab.	Wright Fld., Ohio
Lt. Col. M. Brennan-RA 33154	Engines	Powerplant Lab.	Wright Fld., Ohio
Maj. R. D. Stringer	Engines	Powerplant Lab.	Wright Fld., Ohio
Lt. Comdr. W. Dillard (USN)	Engines	Bureau of Aero.	U.S. Navy
Mr. E. Skralskis	Structures	Aircraft Lab.	Wright Fld., Ohio
Lt. M. G. McKinney (USN)	Structures	Bureau of Aero.	U.S. Navy

TABLE 2 (CONT'D)

Name	Speciality	Organization	
Pfc. R. Amiot	Structures	Aircraft Lab.	Wright Fld., Ohio
Mr. J. Wood	Structures	Aircraft Lab.	Wright Fld., Ohio
Lt. G. Johnson	Engines	Powerplant	Wright Fld., Ohio
Cpl. A. Howes	Structures	Aircraft Lab.	Wright Fld., Ohio
Pfc. H. Miller	Engines	Powerplant Lab.	Wright Fld., Ohio
Pfc. B. Coffman	Structures	Aircraft Lab.	Wright Fld., Ohio
~~Lt. R. Rolstan~~	Engines	A&A Division	Aberdeen Prov. Gd.
Capt. D. Miller	Structures	A&A Division	Aberdeen Prov. Gd.
Lt. A. B. Thomas	Structures	A&A Division	Aberdeen Prov. Gd.
Assistant Assessors			
M/Sgt. A. Curry	Structures	Middletown Air Depot	
T/Sgt. M. C. Murphey	Structures	Middletown Air Depot	
M/Sgt. J. P. Porter	Structures	Middletown Air Depot	
M/Sgt. A. J. Bezek	Engines	Middletown Air Depot	
Crew Chiefs			
M/Sgt. O'Malley			
M/Sgt. Bailey			
M/Sgt. McCormick			
M/Sgt. Brosius			
M/Sgt. LaForge			
M/Sgt. Snyder			
Proof Directors			
Mr. S. P. Willan (Project Engineer)			
Mr. F. E. Watts			
Mr. A. Pillersdorf			
Mr. A. S. Galko			
Mr. J. L. Owens			
~~Mr. S. H. Tucker~~			
Mr. H. L. Rosenburg			
~~Mr. F. X. Hartman~~			

VULNERABILITY OF COMPONENTS

In this section of the report will be described the vulnerability of various aircraft components as obtained from firings in the Optimum Caliber Program.

1. Engines

Firings against running engines expended 102 B-25 and 24 P-38 engines in the period covered by this report. In addition 15 P-47 and 12 B-17 engines had been previously expended and the results summarized in BRL M 437, 1 July 1946.

a. Description of Targets

The B-25J medium bomber is a mid-wing land monoplane. Two radial air-cooled Wright engines, Series R-2600-13, or -29, drive the three-bladed full-feathering Hamilton Standard Hydromatic propellers. Each engine is equipped with its own fuel and oil system. The 14 cylinders are attached to the crank case in two rows of seven cylinders each. Ignition is supplied by two Compensated Scintilla SF-14LN-

3 magnetors attached to the supercharger rear housing cover. The right hand magneto fires the front spark plugs and the left hand magneto fires the rear spark plugs. Views of the B-25J and the R-2600 engine, the oil and fuel system are pictures in Figs. B1-B4, Appendix B.

The P-38L is a twin-boom, single place monoplane fighter powered by two 12 cylinder "V" type liquid-cooled Allison engines. The left engine is a type V-1710-173 with counterclockwise propeller rotation. The right engine is a type V-1710-111 with clockwise propeller rotation. Two G.E. type B-33 exhaust-driven turbo superchargers are mounted in each forward boom. A Curtiss electric, full feathering, three bladed propeller is installed in each engine. Each engine ignition system consists of a dual, high tension magneto, booster coil, two distributors, ignition harness, 24 spark plugs and an ignition switch. The engines are liquid-cooled with ethylene glycol by separate cooling systems. An independent pressure-lubrication system provides oil for each engine. Included in each system is an oil supply tank, pressure pump, oil strainer, scavenger pump and associated accessories. Views of the P-38 airplane and its engines are presented in Figs. B5-B8, Appendix B.

The P-59 Airacomet fighter is a single place, midwing, land monoplane powered by two General Electric I-16 Jet Propulsion Units. Thrust is obtained by jet propulsion. The I-16 is an internal combustion gas turbine engine (see Figs B9-B12, Appendix B). Each engine has a controllable speed centrifugal compressor with double-flow impeller. This compressor is mounted on anti-friction bearings on the same shaft as the turbine. The compressor takes in the rammed air from the engine nacelle, compresses it, and discharges it into the 10 combustion chambers. Here, it is mixed with kerosene sprayed under high pressure into the aft end of each chamber, and the resulting mixture burns with a very hot, continuous fire in a similar manner to the continuous fire in an oil furnace. Since the fire is continuous, no spark plugs are needed except for starting. The hot exhaust gases of this combustion pass, by means of a duct in the forward end of each burner, through the turbine wheel, causing it to revolve continuously. The compressor, being on the other end of the shaft (which is the only major moving part in the engine) is thereby driven by the turbine in a self-sustaining process which continues as long as fuel and air are available. The hot gases pass through the turbine, their direction of flow is straightened by the tailcone, and they then rush out of the tailpipe at extreme high velocity. The speed of the compressor is controlled by the throttle, which regulates the amount of fuel injected into the combustion chambers, and consequently the flow of gases through the turbine.

A description of the P-47 (R-2800) and the B-17 (R-1820) engines and a detailed description of the method used in firing against engines, are contained in BRL Memorandum Report 437. Views of these engines are presented in Figs. 13-17, Appendix B.

b. Method of Firing and Assessment

1) Reciprocating Engines

The order with which rounds impact on the various parts of an engine is important in any determination of the probability of a kill, because of possible cumulative damage. For this reason the engine is divided into a number of sections of equal presented areas to which random numbers are assigned.

Rounds are aimed at [illegible] areas in random order. Each engine is given a new set of random numbers which govern instructions to the gunner as to the aiming point for any particular round. Single shot damage is assessed and in addition an independent assessment of the cumulative damage for all rounds is made.

Modification of the definitions of numerical assessments must be made for damage to an engine of a multi-engined plane. If assessments of such engine damage were made as applied to the complete plane one would not have a sensitive measure of damage since an immediate kill on the engine would not result in an immediate kill on the plane or even necessarily in any "A" or "B" damage to the aircraft. Hence for multi-engined aircraft, "A" and "B" assessments of engine damage are referred to the killing of the engine itself within the respective time intervals and not to the entire aircraft. The results may then be properly combined mathematically to obtain probabilities for killing the plane by hits on more than one engine. The "C" and "E" assessments in these cases still refer to the aircraft as a whole.

2) Jet Engines

Firing against jet-propulsion units installed in aircraft requires a procedure different from that for reciprocating engines. This is necessary because the supply of jet units for these tests is limited and it is therefore required to repair damaged units after each round, if practicable. In order to obtain a maximum number of single-shot assessments, firings are conducted against the least vulnerable components first. Firing for compound damage is here sacrificed in order to obtain as many single-shot assessments as possible. The information obtained from such firings, while not very extensive for any one caliber, will be of great value when coupled with controlled damage experiments conducted at Wright Field by the Air Materiel Command of the Army Air Forces.

The physical set-up for firing of jet units differs from that for firing reciprocating engines. A slave engine is used to provide a ram for the unit. In addition, certain instrumental readings become necessary for damage assessment. The r.p.m. of the turbine, the tailpipe temperature and a measure of thrust loss are obtained. The firing position for firings against P-59 engines is shown in Fig. B18, Appendix B.

c. Supplementary Tests

BRLM 437 contains a description of a test to determine engine running time after the loss of oil. This test was made with an R-2300 (P-47) engine and with two R-2600 (B-25) engines. In view of these tests on engines with oil completely shut off, the assessors considered they were justified in assessing oil loss at not more than "B" damage, regardless of amount.

Similar tests were run with liquid-cooled V-1710 (P-38) engines to determine the running time after loss of coolant and oil. The assessors' description follows:

"Both engines were given a preflight and daily inspection and each engine was run for approximately 5 minutes until the oil temperature, manifold pressure and coolant temperature readings were the same as if the aircraft was in flight and making its attack.

The right engine was then shut off and the coolant drained from the engine. The engine was restarted and run at 2300 r.p.m. The engine started to cut and slow badly after 3 1/2 minutes. After 14 minutes of continuous running the engine caught fire. It stopped from fire damage after 18 minutes.

The left engine was then drained of both oil and coolant and run at 2300 r.p.m. It started losing power after 2 1/4 minutes and seized after 2 1/2 minutes running time."

d. Results of Firings Against Engines

1) Confidence Intervals

The primary limitation on any conclusions to be drawn from firings to date is that of sample size. It is desirable to measure the probable influence of sampling fluctuations, and this can be done by finding the confidence limits for the estimates of damage. Confidence limits are values based on a sample which will include between them the true probability of damage a preassigned fraction of the time (called the confidence coefficient) in repeated sampling.[1] Most of the results in this report are presented in the form of probabilities. These probabilities are usually quite small and in general are sufficiently distant from the value of 50% so as to make the underlying binomial distribution an asymmetrical one. It is for this reason that confidence intervals rather than probable or standard errors are used to described the probable influence of sampling fluctuations. The non-normality of the binomial distribution for small sample sizes and extreme values of probabilities renders the standard error confusing as a descriptive measure for the purposes of this report. Moreover, a comparison of confidence intervals for results obtained in two different tests serves as a useful guide to the statistical significance of differences in averages obtained from the two samples. The confidence intervals used in this report are based on a confidence coefficient of 95%. Thus 2.5% of the time the true probabilities of a kill would lie below our lower confidence interval and 2.5% of the time they would lie above our upper confidence interval.

2) Description of Results for Reciprocating Engines

The damage assessments to various types of engines are summarized in Tables C1 through C9, Appendix C. The results are illustrated in Figs. 1 through 7. The "number of hits" referred to in the tables of Appendix C pertain to the number of fair impacts on the projected area of the engine. A fair impact is one whose effect could be assessed as single shot damage.

It is evident from the firings against engines observed to date that the cumulative "A" and "B" kills were largely the result of damage caused by a single round. This fact, coupled with the relatively small probability of getting large numbers of rounds into one engine in combat, resulted in the decision to omit analysis of cumulative engine damage from the present report. It is hoped that the effect of cumulative damage to engines may be fully summarized in a report on engine damage when all firings against engines are completed.

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1 For a fuller discussion of the interpretation and methods of computing confidence intervals the reader is referred to "Mathematical Statistics", by S. S. Wilks, Princeton University Press, Princeton, N. J., 1943, pps. 122-123.

The tables of Appendix C and the corresponding figures serve to illustrate the importance to engine vulnerability of the line of fire, and of the engine type. Thus the B-25 engine displays greater vulnerability, especially noticeable for the Cal. 0.50 API-T, M20 and the 37mm HE, M54, when fired upon from the rear and below as compared to fire from rear and above or from the front.

The various air-cooled reciprocating type engines (B-25, P-47, B-17) display in general the same order of vulnerability. The combined results for these three type of engines are presented in Table C9, Appendix C and Figs. 5 and 6. However, the liquid-cooled reciprocating engines (P-38) and the jet engines (P-59) are far more vulnerable than the air-cooled reciprocating engines (see Tables C1-C10, Figs. 1-7). The air-cooled engines suffer far greater "B" damage than "A" largely due to the vulnerability of the lubrication system. Large oil damage, obtained quite often with even the smallest caliber used in the program, will not result in an engine kill in five minutes or less ("A" damage) but will definitely cause the engine to stop within the two hour limit defined for "B" damage. The liquid-cooled engine has the additional handicap of the cooling system. The cooling system contributes to "B" damage when damage causes loss of coolant. In addition, it represents a source of "A" damage in that the coolant, ethylene glycol, is inflammable and will support fires large enough for an "A" kill.

Significant too is the relatively low vulnerability of the B-25 engines when fired from the rear and above (except to the German 3cm.) The installation affords large protection to the engines and most rounds are effectively rendered harmless by the intervening structure, especially the main spar. The German 3 cm, a high capacity round, was assembled with delay fuze during most of the B-25 engine firings from the rear whereas it had a superquick fuze for firings from the front. The greater damage with delay fuze was apparent throughout the firings and accounts for the fact that this round appeared more effective against engines from the rear and above than front and below. Firings are now being conducted with both superquick and delay fuzes for this round and the comparison of effectiveness will be presented upon their completion. Also of interest is the comparison of the two Cal. 0.60 rounds (API and Incendiary) against the liquid-cooled P-38 engine. The armor-piercing incendiary round is relatively more effective when fired from the front, where it can penetrate to the cooling system more easily than the incendiary round. However the incendiary ammunition is more effective for firing from the rear and above with the cooling system easily accessible to it.

3) Engine Component Damage

One important by-product of the optimum caliber firings is information regarding the relative vulnerabilities of the various aircraft components and sub-components. By use of a coding system on the firing records the damage to engine components was classified. The results are presented in Tables C12 through C19 in Appendix C. There are listed in these tables, for each type of engine and ammunition employed, the relative frequency of hits on the component (several may be hit with one impact) and the maximum, the minimum and the average assessment assigned to hits on the component. Classification was made with respect to the components themselves and also with respect to the functional system affected by the damage. Thus the oil cooler is a component which affects the lubrication system.

In general, the most prevalent serious functional damage to air-cooled engines is to the lubrication system. Liquid-cooled engines are, in addition, very susceptible to coolant damage. It should be remembered that impacts were distributed randomly over the presented area of the engine. Therefore, if some obviously vulnerable part is not reflected as a serious source of damage, it is probably too small or well-protected to be hit often.

4) Vulnerability of Jet Engines

44 General Electric I-16 jet engines installed in 22 P-59 twin-jet fighters have been received for use in the Optimum Caliber Program. Of this number a total of 5 planes or 10 individual jet units have been expended. Because of the limited number of jet engines available for test, the method of firing has been modified. The least vulnerable areas of the engines are fired upon first. Subsequent rounds are aimed at areas of increasing vulnerability until a single shot kill is obtained. Table C10, Appendix C, and Fig. 7 summarize the results of these firings.

Upon the instructions from the Office of the Chief of Ordnance, the Cal. 0.50, API-T, M20 firings were supplemented by firings of the Cal. 0.50, Inc. M23, and the Cal. 0.50, API, T49. The latter two types are 500 grain projectiles with a muzzle velocity of about 3450 f/s compared with the 675 grain M20 projectile, which has a muzzle velocity of about 2950 f/s. The heavy API, M20 and the light Incendiary M23 appear to be equally effective, both projectiles being superior to the light API, T49 projectile.

It is considered that the vulnerability of the jet engines is sufficiently important to warrant a detailed account of damage. Table C11 presents the chief sources of damage for each impact on the engine projected areas with the various types of ammunition employed. The German 3 cm high capacity HE shell was fired into a dead engine. The resulting structural damage to the engine clearly indicated an immediate kill. This round contains the equivalent of 1/4 lb. of TNT and the blast damage was of itself sufficient for a kill.

Both the 20mm HEI, M97 and the German 3 cm shell were statically detonated in various positions inside the tailpipe of dead I-16 engines. Since no information is presently available regarding the significance of various sizes of holes along the tailpipe, it is proposed to conduct a controlled tailpipe damage experiment which will yield the loss in thrust resulting for such damage and also the temperature distribution in the vicinity of such holes. Tailpipe damage may thus be evaluated for various types of shell without the expenditure of any of the scarce jet units.

Controlled burner damage experiments have been conducted by the Air Materiel Command, Army Air Forces at Wright Fld., Ohio.[1] From these and other battle damage tests,[2, 3, 4] it is hoped

[1] "Battle Damage to a General Electric J-31 (I-16) Jet Engine by Actual and Simulated Gunfire", Air Technical Service Command, Army Air Forces, TSEPP-506-116, 26 June 1946.

[2] "Heat, Fire and Battle Damage Characteristics of Turbo-Jet Installations", Air Technical Service Command, Army Air Forces, TSEPL-525-299, 1 September 1945.

[3] "P-80 Battle Damage Tests", ATSG, Wright Fld., Ohio, 9 October 1946.

[4] "Vulnerability of Turbine Engines-Second Running Trial", Orfordness Research Station, O.R.S. F. T357 June 1946.

eventually to obtain reliable estimates of the vulnerability of turbo-jet components and the overall vulnerability of different models of turbo-jet engines to various types of ammunition.

It is hoped to present a detailed analysis and summary of jet engine damage tests conducted at Aberdeen and elsewhere upon completion of the current series of firings. Study of the effect of blast and fragments in addition to impacting missiles is contemplated. The probable effect of changes in turbo-jet design and of multiple jet nacelle installation on jet vulnerability will also be treated. In particular, the large contribution of fuel damage to the I-16 vulnerability must be considered for any extrapolation to other jet engine types, such as the I-40, where there are smaller presented areas of fuel lines. The Aberdeen Proving Ground firing records contain highly detailed descriptions of damage to the G.E. I-16.

2. Fuel Tanks

A total of 26 P-38, 4 P-59 and 13 B-25 aircraft were expended in firings against fuel tanks in the period covered by this report. 53 A-35 aircraft previously expended in fuel tank firings were reported in BRL Memo. Report 437.

For the purposes of this program, the fuel system is defined as the fuel tanks or cells and fuel lines exclusive of fuel lines in the engine accessories section. Damage to the latter is assessed with engine damage.

a. Description of Targets

The B-25 medium bomber has an independent fuel system provided for each engine (see Figure D1, Appendix D). The chief sources of fuel supply are four large self-sealing wing tanks called the main tanks. There are two main tanks located in each wing center section between the fuselage and the engine nacelle. The front and rear main tanks in each wing are interconnected by a line which extends from the rear tank to an adapter mounted on the front tank, to which an electrically operated booster pump is attached. Six additional fuel cells are provided as auxiliary tanks, three interconnected cells in each outboard section of the wing. The B-25 S is also sometimes equipped with a self-sealing fixed bomb bay tank, located in the upper portion of the bomb bay. A bomb bay droppable tank constructed of aluminum alloy is often bolted to the support of the fixed bomb bay tank. It is assumed that the bomber under attack in this report does not contain either the fixed or the droppable bomb bay tanks. The front main tanks each have a capacity of 184 gallons, the rear main tanks each have a capacity of 151 gallons, and the three auxiliary tanks in each wing have a combined capacity of 152 gallons.

The P-38 fighter has an independent fuel system provided for each engine (see Fig. D2, Appendix D). The chief sources of fuel supply are two main tanks, one inboard on each wing, each with a capacity of 93 U.S. gallons. In addition there are in each wing an outer wing tank with a capacity of 55 gallons, a reserve tank with a capacity of 60 gallons and a droppable tank with a capacity of 165 gallons. All the tanks with the exception of the droppable tank were used in the firing tests. All the tanks used were self-sealing. Fuel is supplied to each engine by an engine driven fuel pump and an individual booster pump for each tank. These tanks were used for both gasoline and kerosene firings.

The P-59 jet aircraft used in the tests contain four self-sealing fuel cells in each wing having a combined capacity of 290 U.S. gallons (see Fig. D3, Appendix D). Provisions are made to carry one 75, 110, or 150 gallon auxiliary fuel tank under each wing. The fuel is supplied from the wing to the engine driven pump by conventional electric booster pump. The main engine-driven fuel pump steps the fuel pressure up as high as 500 psi. "Line losses" cause this pressure to drop to about 300 psi by the time it gets to the engine. High pressure stopcocks operate instantaneously to provide a sudden spurt of high pressure fuel (45 to 50 psi) to the burners for prompt starting and provide the quickest and most positive means of shutting off the engines.

b. Method of Firing and Assessment

All fuel tank firings conducted during the period covered by this report were against fully loaded self-sealing fuel cells. Over the target the plane usually will have almost half of its fuel expended, and half the cells are likely to be empty or nearly so. Firings against the A-35 fuel cells (summarized in first report) were conducted with half the fuel cells surviced with only 7 gallons of gasoline, to give a saturated vapor. However, the combustibility of the vapor-air mixture is critically dependent upon the temperature. The mixtures in the freely vented cells are too rich for combustibility at temperatures above 20° F. It was evident from the A-35 firings that outside of the dangerous temperature zone these "empty" cells contributed negligibly to vulnerability. For JP-1 kerosene the dangerous temperature zone exists at about 100°F. and higher (see Fig. 8[1]). Temperatures at Aberdeen are too high for explosions in gasoline and too low for explosions in JP-1 kerosene vapor-filled vented tanks to be expected.

For most fuel tank firings included in this program, rounds are fired singly and assesment for any cell is made after each impact on it. All rounds, excepting high explosive or high explosive incendiary, are aimed at the projected area of the fuel tanks. The HE or HEI rounds are, in addition, aimed at varying distances from the projected area in order to determine the contours about the tanks within which the round could inflict fuel cell damage.

Present fuel tank firings include the installation of a "slave" engine which provides a flow of air past the wing such as would be obtained in flight. Previously, assessment of fire damage was handicapped by the lack of an air stream. Small fires may be blown out by such a stream. Information obtained from the Army Air Forces indicates that a speed of 110 mph IAS could extinguish a surface fire (which does not burn more than 3 seconds in streams of 200 mph or greater). In no case could an internal fire be blown out by such a stream.

Particular care is taken by the assessors in designating as a compound assessment one given for a round impacting on a damaged tank or in an area into which fuel has leaked. The leakage from a full fuel cell which is obtained without accompanying fire is assessed according to the amount of fuel re-

[1]This chart is reproduced from one obtained from Power Plant Laboratory, Air Materiel Command, Wright Fld., Ohio. A series of reports have been issued by this laboratory which contain detailed data on combustible ranges of temperature for many types of aircraft fuels. The titles of these reports were not available at the time of writing. Also see TED No. NPG. 2599 - "Simplified Tests to Determine the Vulnerability of Jet Propelled Aircraft Fuels," U. S. Naval Proving Ground, Dahlgren, Va.

maining for the trip back to home base. The subsequent round into such a cell is not considered a fair round for the calculation of single shot probability of damage. However, such a round will yield useful information for the estimation of compound damage based on the probabilities of obtaining a fire when a round is fired into an already leaking cell.

Fuel tank firings are the most costly from the point of view of number of fair hits per aircraft expended. Because of the ever present danger of losing the entire plane before all the available fuel tank information is obtained, it is considered best to fire at each loaded fuel cell once until all cells have been hit. Thereupon, if these first rounds have not demolished the plane, subsequent rounds are fired in order to obtain the probability of getting cumulative damage where leakage already exists.

c. Supplementary Tests

Several tests now in progress and also to be conducted in the near future are designed to supplement information obtained from firings against aircraft. Such tests are concerned with the actual mechanics of fuel tank ignition and include ignition of fuel tanks by fragments. One such test, recently completed, involved the detonation of a 20mm high explosive incendiary round in the middle of a fully loaded B-17 main fuel tank. The lack of fire served to verify and emphasize the importance of ignition of the vaporized fuel at the surface of the tank.

d. Results of Firings Against Fuel Tanks

The single-shot damage data on gasoline and kerosene-filled fuel tanks are summarized in Table E1, Appendix E. Table E2 lists the corresponding compound damage. Tables E1 and E2 include all fuel tank information obtained in the period ending 1 December 1946 and repeats, for purposes of comparison, results of firings against A-35 fuel tanks reported in detail in BRL Memo. 437. There have been a large number of firings against fuel tanks at 500, 1000 and 2000 yards, both from the front and from the rear, in the period since 1 December 1946 and it is hoped to summarize these in a later report.

Tables E1 and E2 give the total number of hits obtained on the projected area of fully loaded fuel cells and the hits on the projected area of empty fuel cells obtained in B-25 structure firings. The next column in both tables gives the number of hits on the projected area resulting in complete penetration of at least one wall of a fuel cell. The difference in the two columns represents hits on the projected area which did not result in cell penetration due to ricochet, break-up of round, or in the case of the HE shell, ricochet or stopping of fragments. The high values of $\frac{CP}{H}$, or penetrations per hit on projected area, for the compound assessments are due to the fact that leakage of a tank may result in a fire upon impact of a projectile even though it would not penetrate the cell. Although the resulting fire obscured penetration all compound fires were classed as cell penetrations. The single-shot penetrations only are used in later calculations.

The next two columns in Table E1 list respectively the numbers of hits resulting in fires (of duration greater than 1 second) and in leakage without fire. The relative numbers of fires and leakage per hit on projected area and per penetration and also the penetrations per hit on projected area are listed in the next five columns in Table E1. There does not appear to be any significant difference between the vulnerability of kerosene-filled cells in the P-38 and P-59. The smaller probability of obtaining fires with kerosene as against gasoline is significant. In fact, no single-shot kerosene fires were obtained with the Cal. 0.50 API-T, M20 and very few with the Cal. 0.50 Inc M23. However, the lower volatility of the kerosene does not reduce the probability of obtaining compound fires (see Table E2) and, once leakage has occurred, subsequent impact would seem to cause a fire as easily as with gasoline. Although there were too few fair impacts obtained against the A-35 fuel cell significantly to demonstrate their greater vulnerability, nevertheless physical reasons exist for this to be so. The main tank only was fully loaded in the A-35 firings and this tank is a relatively tall fuselage tank. Consequently, rounds usually impacted on the side of the tank rather than on top in firing from the rear, with greater damage due to available fuel pressure at the bullet entrance hole.

The last four columns in Table E1 list the average single-shot "A" and "B" assessments given to those hits causing fires and to those hits causing leakage without fire.

The last two columns in Table E2 list the average "A" and "B" assessments given to fires obtained in previously damaged cells. In each case the assessments pertain to the corresponding type of aircraft. It is clear that the relative frequency of fuel fires and leakage is not sufficient as a description of fuel tank vulnerability. The severity of fires and the location of fuel tanks are important to the overall vulnerability of the fuel system. In general, it appears that the higher the probability of causing a fire, the higher the severity of fires when they do occur. The Cal. 0.50 ammunition caused no single-shot fires which had any chance of causing the plane to crash within five minutes. Among the small calibers, only the Cal. 0.60 displayed the ability to cause any appreciable single-shot "A" damage through fires. This may be due to the relatively high striking velocity for this caliber, resulting in more two-wall penetrations of fuel cells. The 20mm rounds resulted in fires causing good "B" damage but not enough for high "A". It is expected that this caliber will show up much better in firings against the lower surface of the wing. The higher blast effect from the 20mm rounds results in larger holes on entry into the top of the fuel cell, but no damage to the lower part of cell in contrast to the effect of the Cal. 0.60. The resulting fires then are relatively weak, not being fed by a stream of fuel. Often they are blown out by the slip stream of air provided by the slave engine. In firings from the front and below, it is expected that fires caused by the 20mm rounds will prove much more damaging.

The firings against empty B-25 cells are tabulated in order to increase the sample size for penetrations of cell per hits on projected area.

3. Structures

All assessments of damage from impacting projectiles not included under fuel tanks and engines are defined as "structures" assessments. Damage to armament, personnel, oxygen bottles, instruments, spars, surface, controls all come under this heading. 12 P-47 aircraft were expended in structures firing up to 10 May 1946 and results are summarized in the first optimum caliber report. The present report shows results for "structures" firings against 35 B-25's, 17 from the front and below, and 18 from the rear and above.

a. Description of Target

Wooden dummy personnel silhouettes constructed of 7/8" sugar pine replaced the foot-

[illegible] dummies used in the early P-47 structures firings. The charge permitted an objective measure of personnel damage based on current knowledge of wound ballistics. The dummies were fitted with steel helmets, flak vests and parachutes. Location of impacts on the dummy are made by means of numbered 3 inch squares. Each plane was equipped with 12 or 13 Cal. 0.50 machine guns, 4000 rounds of live Cal. 0.50 ammunition in boxes and ammunition chutes and live flares, drift and distress signals. Twelve inert-loaded 100 lb. G.P. bombs were placed in position in the bomb bay. Low-pressure type [illegible] oxygen bottles were placed in position. These bottles were loaded to the same pressure in each plane, and the pressure varied from plane to plane, from 50 psi to 450 psi. Main fuel cells were water-filled and auxiliary tanks were empty for the structures firings. The engines had been previously expended during the engine phase of the test.

The entire B-25 was marked off in five-foot zones. The zones aided in identification of impacts and also served as a basis for removing bias from unequal distributions of hits over the projected area of the planes.

b. Method of Firing and Assessment

Structure firing is the most time-consuming of all phases [illegible] the part of the plane and since a large number of hits are required for each plane. [illegible] good deal of technical knowledge and experience are especially required of structures assessors [illegible] in this phase is usually not dynamic and a more difficult judgment is required to determine [illegible] plane in flight, than in the case of engines or fuel.

Chiefly because of the non-dynamic nature of the target during structures firings the order of rounds impacting in various places is not very important (as it is with the running engine). During the initial firings on the plane the attempt is made to distribute evenly as many rounds as possible over the presented area of the target, with little or no overlapping of damage. [illegible] rounds are used [illegible] single shot probability of a kill. After these rounds are assessed, further firing is conducted to obtain compound damage resulting from two or more impacts. The number of compound hits obtained per zone is governed by the significance of the areas as a source of compound damage, by the homogeneity of the area and by the likelihood of getting the requisite number of hits into the area.

Damage to fuel tanks obtained during structures firing is described, but no assessment is given since they are not filled with fuel. Similarly, description is made only of engine damage [illegible] during structure firings.

c. Supplementary Tests

Occasionally there will arise the need for a supplementary structures test. [illegible] tests were been conducted, for example, to determine the effect of blast on modified B-17 structures [illegible] results of interest to aircraft design were obtained.[1] Tests are also required to determine [illegible] [illegible] to [illegible] the different incendiary or HE projectiles employed. A series of supplemen-

[1] "The Damage Effect of Small TNT Bare Charges Placed Inside Standard and Modified B-17 Fuselages", [illegible], Ballistic Research Laboratories Memorandum Report No. 442.

tary tests were conducted against the expended P-47 aircraft to determine the contours of the fuselage within which fuel tank penetration could be obtained. The information obtained from the limited number of P-47 structures firings was insufficient to obtain contours of any reliability. The data obtained from this supplementary test was used to obtain the overall probability of a kill on the P-47, as described later in this report.

d. Blast Tests

A large series of tests has been conducted at Aberdeen to determine the effect of blast from bare and cased charges on aircraft. These tests provide a basis for damage estimates for blast damage from high explosive shell with small delay or superquick fuzes. In addition they provide data on the effect of blast from larger charges detonated at various distances from the target aircraft.[2] Of importance to impact firings is the fact that by means of these blast firings damage estimates may be made for shell not used in the optimum caliber firings, even shell in the design stage of development. Similar blast tests have been conducted against B-17 engines and will be conducted also against loaded fuel cells. It is hoped to present results in these other phases in the near future.

e. Results of Firing Against Structures

Tables F1 and F2 in Appendix F present the average assessments in each structures zone from rear above and from the front. The values in this table include damage to personnel. Results are presented to afford a comparison of damage to any one zone for the several types of ammunition employed. Only the "A" and "B" damage categories have been described in this report. "C" and "E" damage are encountered to a large extent in structures firing and it is hoped that information on the "C" and "E" categories can be presented in a following report on structures damage.

Tables F3 and F4 in Appendix F present the overall structural damage (excluding personnel) for the B-25, from rear, above and front, below. In these tables the single-shot probabilities of "A" and "B" kills are presented with their corresponding 95% confidence intervals. It is with special regard to structures damage that the possibility of reducing the sampling error by knowledge of the structure exists. When it is known, for example, that fairly large areas of wing and fuselage are homogeneous and invulnerable with respect to damage caused by the Cal. 0.50 and possibly the Cal. 0.60, it is not necessary to depend solely upon the sample size for reliability of the results for impacts on these areas. Thus if the upper confidence limit for the size of hole caused by a Cal. 0.50 in the horizontal stabilizer would still be assessed as zero damage, then this may be assumed to have no appreciable sampling error.

In Tables F3 and F4 the probability of an "A" or a "B" structural kill for a hit on the B-25 is obtained by weighting the average probabilities for each of the structural zones (Figure G1) and summing over the plane for all zones with recorded impacts. This procedure tends to remove the bias which would occur if a simple average of all structural hits were made. The bias is due to non-uniformity of impacts with respect to projected area. This would occur if more than a proportionate number of impacts were obtained on a vulnerable zone.

[2] "Report on Tests of the Effect of Blast from Bare and Cased Charges on Aircraft" by James N. Sarmousakis, Ballistic Research Laboratories Report No. 436.

f. Structures Component Damage

As in the case of the engines, a coding system was employed to classify structural component damage. The various aircraft sub-components which constitute the general classes of armor, armament and attack equipment, landing gear and hydraulic systems, supporting surfaces, surface controls, and personnel are thus classified. The contribution of each of the sub-components to the overall vulnerability of the plane may then be obtained.

Damage to structural components of the B-25 and the relative number of times each sub-component was hit are presented in Tables F6 and F7 in Appendix F. These tables are prepared for all calibers fired against B-25 structures from the rear and above and at a range of 500 yards. Similar tables are being prepared for other ranges and lines of fire.

g. Pilot Injuries

The only personnel damage contributing directly to an "A" or "B" kill is that to the pilot of the P-47, and to both pilot and co-pilot of the B-25. For the P-47, firing from the front, the pilot's vulnerability increases as the cosine of the angle θ, the angle between the line of fire and the longitudinal axis of the fuselage. For the line of fire employed in firing against the P-47 the pilot is not well protected (see Figure G2). There were too few impacts for each type of ammunition in the P-47 firings to make a purely objective measure of this type of vulnerability. On firing from the rear and above against the B-25 however, the pilot personnel are relatively well protected (see Fig. G3). For this line of fire, it is possible to obtain pilot hits by impacts in zones F3 and F4. Table F5 presents the numbers of hits obtained in these zones and the number of casualty inflicting hits obtained on the near and far pilot. It will be noted in this table that injury to pilots is not as prevalent with the high explosive rounds as might first be expected. For the line of fire employed, the distance from point of impact to the pilots was large compared with the distance from point of impact to point of functioning. Consequently many hits by high explosive rounds on the projected area of pilot result in no penetration of the dummy pilots. Pilot vulnerability is an important source of aircraft damage. Except for the large high explosive rounds no one round inflicted "A" damage on both pilots; hence the contribution of pilot vulnerability to the overall vulnerability of the B-25 is zero for one hit. Pilot vulnerability becomes important with increasing numbers of hit on the plane. This is illustrated in a later section of the report in which the overall vulnerability of the B-25 is obtained.

SINGLE SHOT PROBABILITY OF "A" DAMAGE FOR HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINES

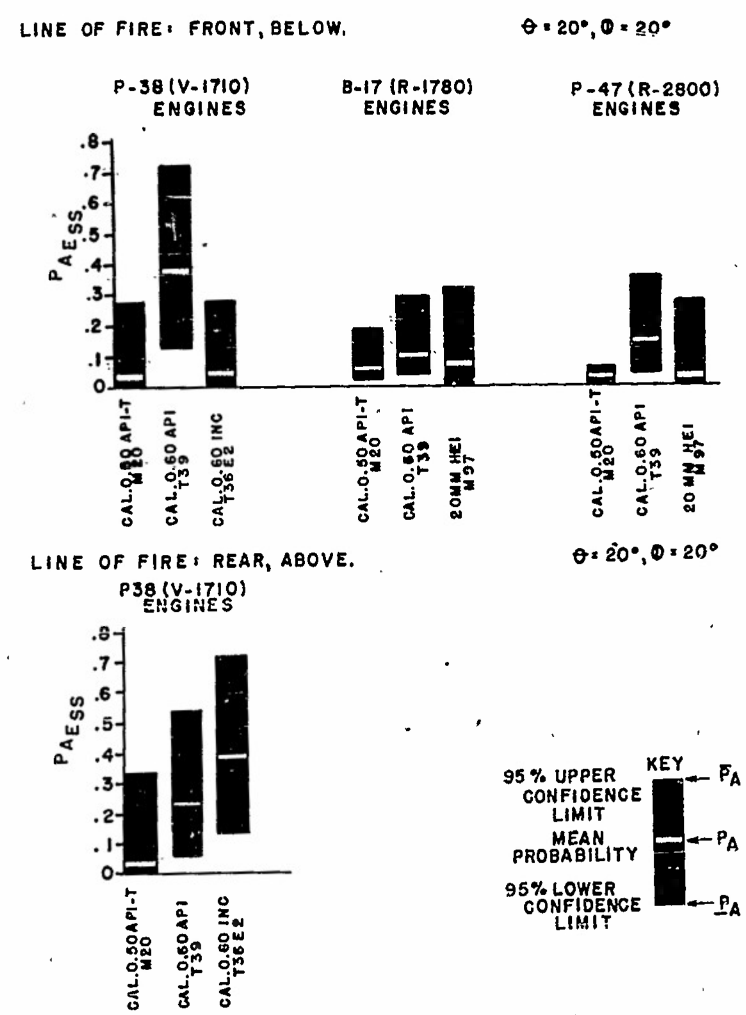


FIGURE I

SINGLE SHOT PROBABILITY OF "B" DAMAGE FOR
HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINES

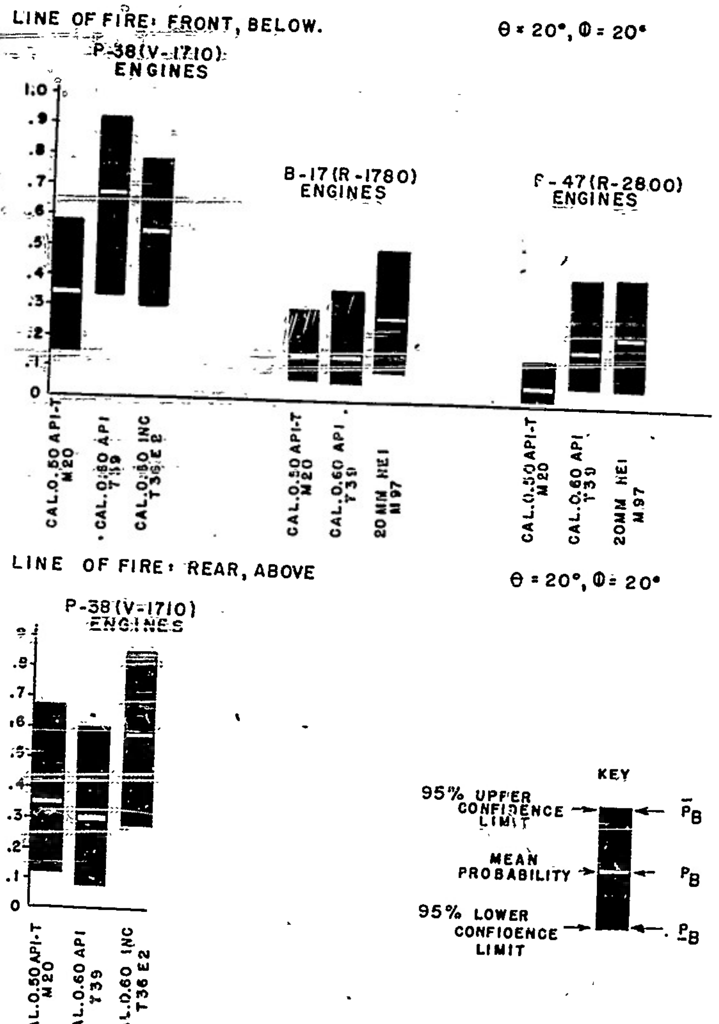


FIGURE 2

SINGLE SHOT PROBABILITY OF "A" DAMAGE FOR
HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINES

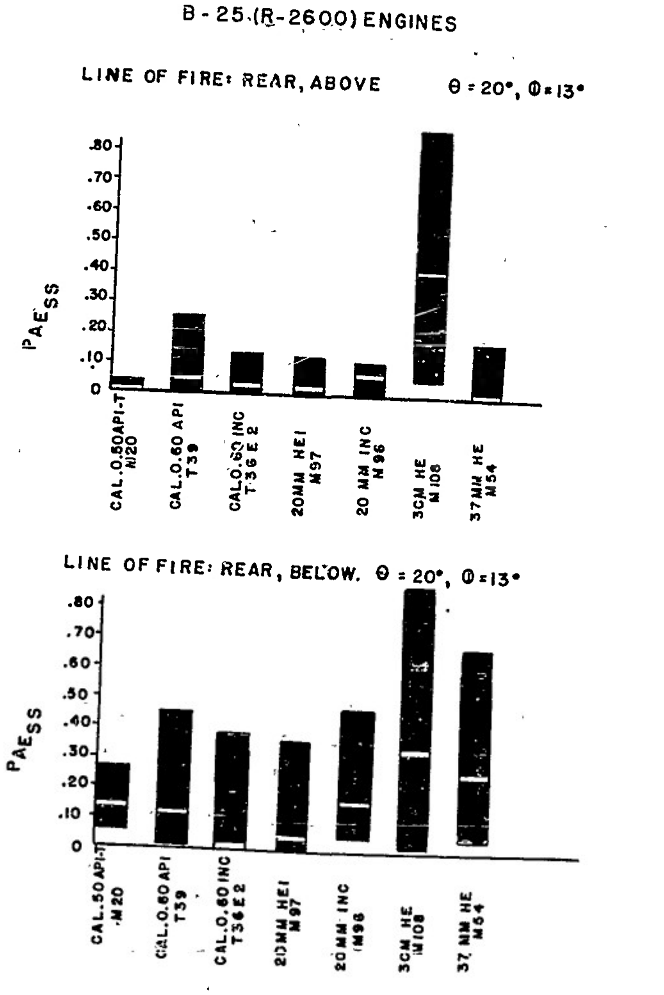
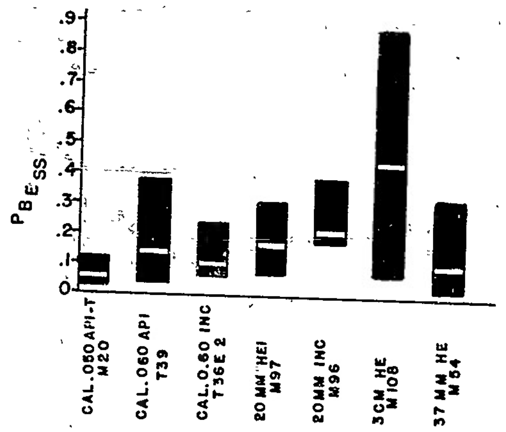


FIGURE 3

SINGLE SHOT PROBABILITY OF "B" DAMAGE FOR HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINES

B-25 (R-2600) ENGINES

LINE OF FIRE: REAR, ABOVE. $\theta = 20°$, $\Phi = 13°$



LINE OF FIRE: REAR, BELOW. $\theta = 20°$, $\Phi = 13°$

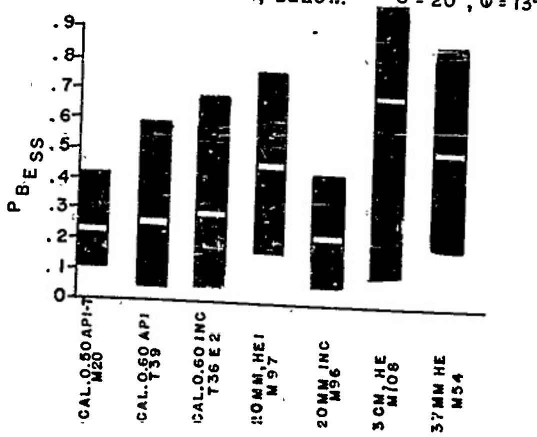
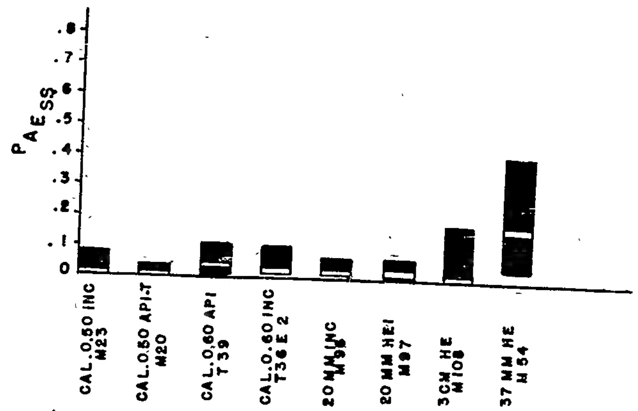


FIGURE 4

SINGLE SHOT PROBABILITY OF "A" DAMAGE FOR HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINES

B-25 (R-2600) ENGINES

LINE OF FIRE: FRONT, BELOW. $\theta = 20°$, $\Phi = 13°$



B25, P-47 AND B17 ENGINES (COMBINED ESTIMATE)

LINE OF FIRE, FRONT, BELOW. $\theta = 20°$, $\Phi = 13°$

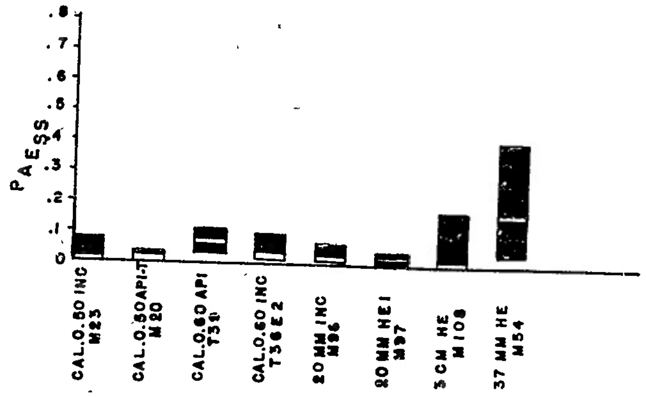


FIGURE 5

SINGLE SHOT PROBABILITY OF "B" DAMAGE FOR HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINES

B-25 (R-2600) ENGINES

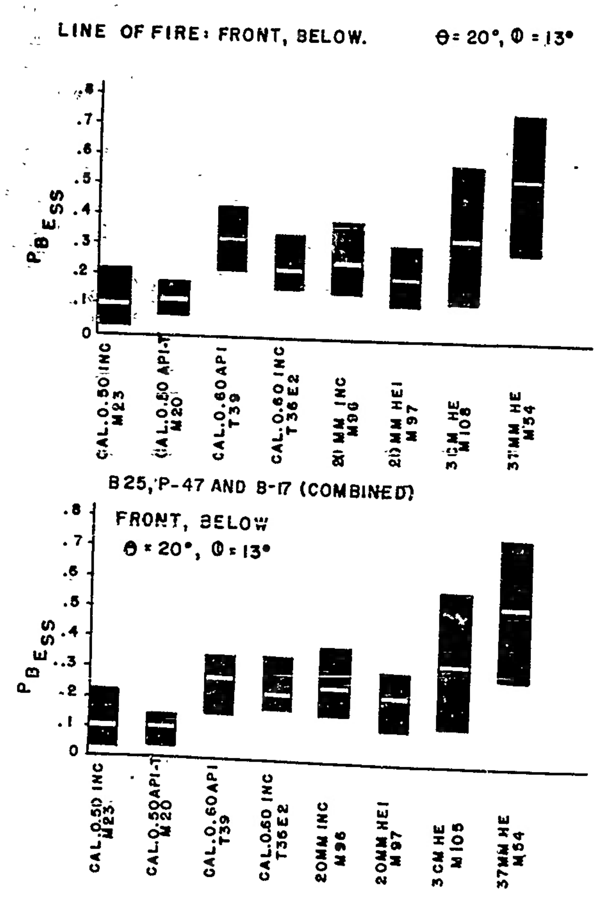


FIGURE 6

SINGLE SHOT PROBABILITY OF "A" AND "B" DAMAGE FOR HITS ON THE PROJECTED AREA OF AIRCRAFT ENGINE P-59 ENGINE (G.E. I-16 JET UNIT)

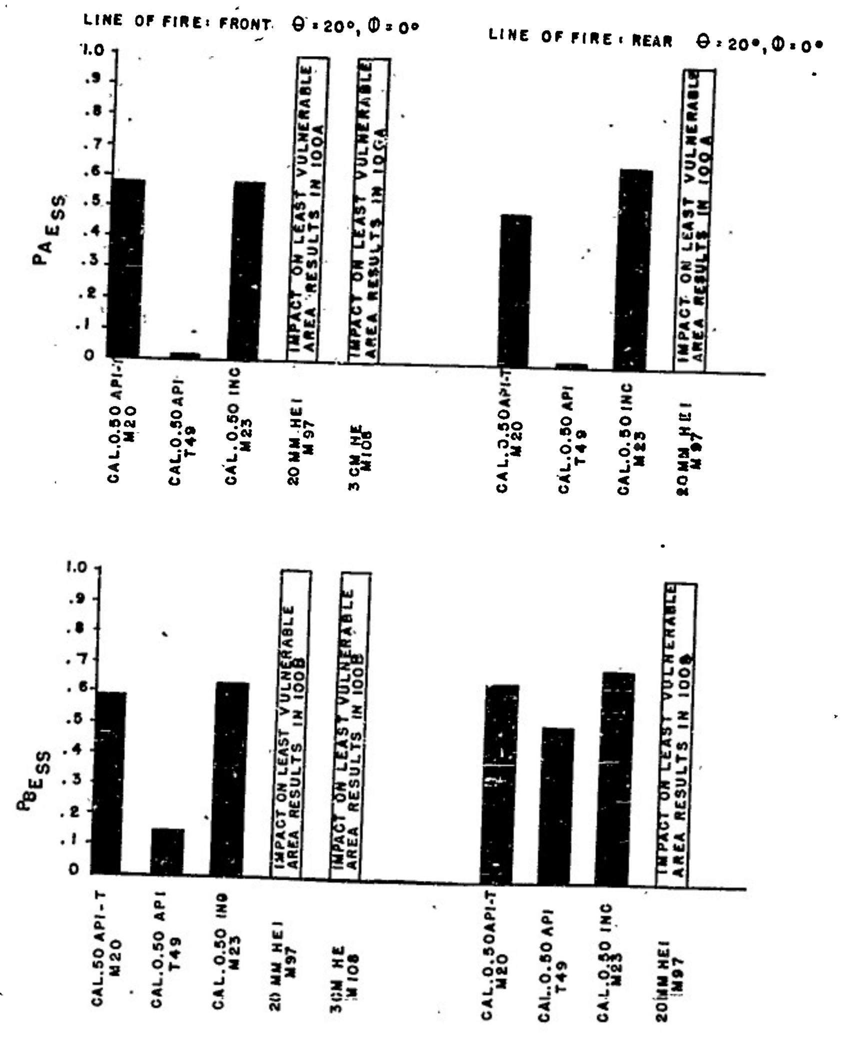


FIGURE 7

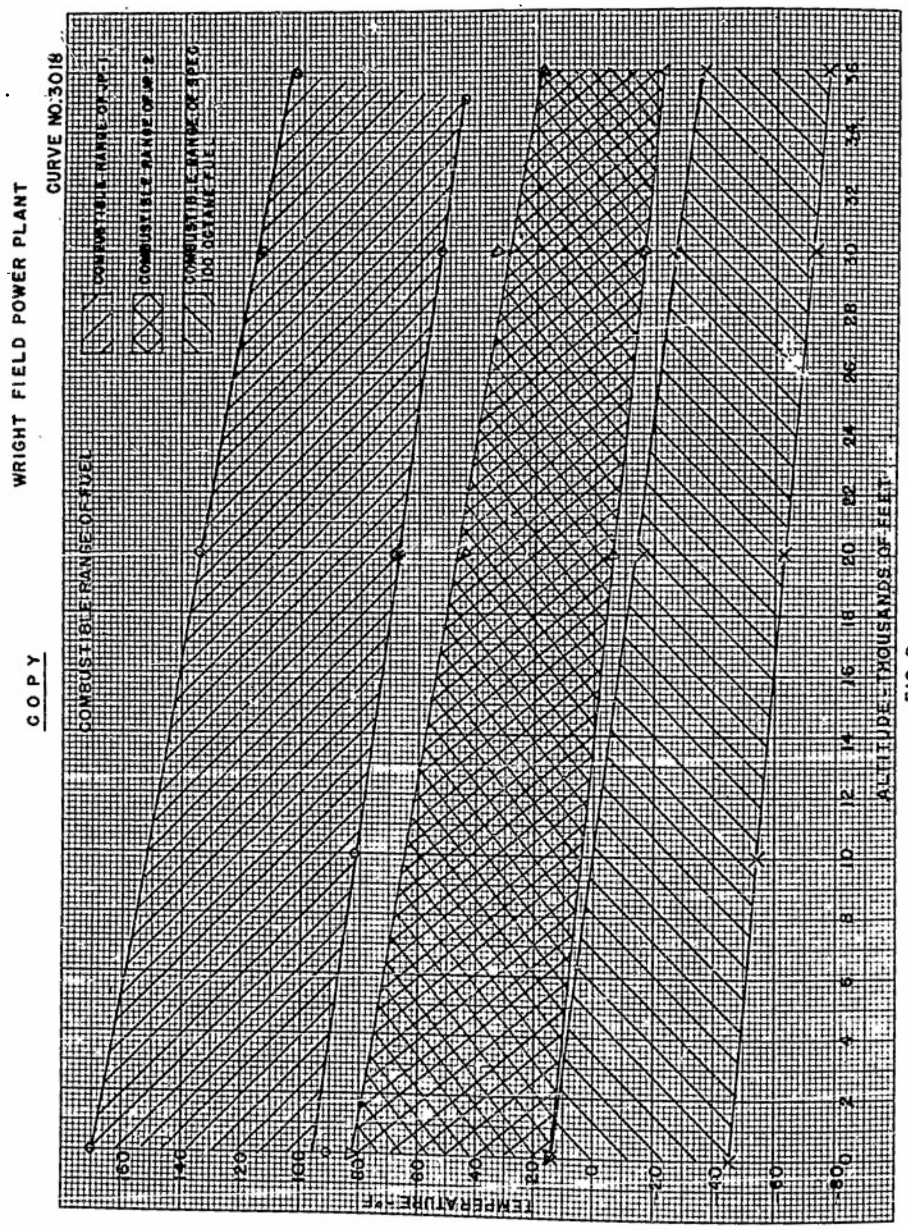


FIG. 8

Part II

VULNERABILITY OF COMPLETE AIRPLANES

PROBABILITY THAT A HIT ON A P-47 FIGHTER CAUSES A KILL

The computation of the expected number of "A" or "B" kills on the P-47 obtained with various weapons and types of ammunition involves the probability that if a hit were obtained on the P-47, it would produce an "A" or "B" kill. This probability is based on results obtained in actual firing and also to some extent on extrapolation from firings against other types of aircraft. The breakdown of this probability for the entire P-47 aircraft into the vulnerability of the various components will indicate the method of calculation. The vulnerability of the P-47 fighter is obtained for fire from the front and below ($\theta = 20°$, $\phi = 20°$), at a range of 500 yards.

Table 3 lists the contribution of the aircraft components considered in the estimate of the overall probabilities of "A" and "B" kills, respectively. This table demonstrates the calculation of the overall probability from the probabilities that a hit on the plane will produce a kill due to damage to the engine, to the structure, to the pilot and to the fuel tanks. The various sources of damage are considered to be independent. The last column of the table lists the so-called "lethal area" for the P-47 for the range, line of fire and particular type of ammunition. The lethal area is a value which is widely used in describing target vulnerability and represents the equivalent totally vulnerable area for the plane. Figures 9 and 10 picture the probabilities of "A" and "B" kills for one hit on the P-47.

The probabilities listed in Table 3 represent single-shot values and do not include the probability of compound damage resulting from two or more hits.

The various component probabilities were obtained as follows:

1. Engine. The probability that a hit on the P-47 will produce a kill due to engine damage, designated as $P_{A_{E_{ss}}}$ and $P_{B_{E_{ss}}}$ in Table 16, was obtained by multiplying the probability that a hit on the engine results in a kill by the relative projected area of the engine to that of the entire plane. This relative area is about .19 for the line of fire employed. The firing against engines was conducted with the engines running and after each round an assessment was made for the damage from that round and also another independent assessment was made of the cumulative damage up to and including that round. The figures used here for the probabilities that a hit on the engine results in a kill are the averages of the single shot assessments and do not include the cumulative effect from more than one hit. Each of the rounds was aimed randomly over the projected area of the engine (which includes the accessory section). Since P-47 structure but not P-47 engine information was available in the case of the cal. 0.60 Inc. T36E2, the 20mm Inc. M96 and the 3cm German thin-walled HE rounds, estimates of P-47 engine damage for these rounds were made from similar firings conducted against B-25 engines. The B-25 engine is of the same general type as the P-47 but has two banks of 7 cylinders each instead of two banks of 9 cylinders each as in the P-47. Also the oil cooler is located in the wing instead of underneath the engine. Tables C1 and C4 illustrate the differences in vulnerability of these two engines.

TABLE 3

Calculation of the Overall Probability that a Hit on the P-47 Produces a Kill

Line of Fire: Front below $\theta = 20°, \phi = 20°$ Range: 500 yards

Caliber and type of ammunition	Probability that a hit on the plane produces an "A" kill due to Engine $P_{A_{E_{ss}}}$	Structure $P_{A_{S_{ss}}}$	Pilot $P_{A_{P_{ss}}}$	Fuel Tanks $P_{A_{F_{ss}}}$	Overall Prob. $1-\pi_{i=E}^{i=F}(1-P_{A_i}) = P_A$	Lethal Area** (ft^2)
0.50, API-T, M20	.001	.005	.010	.001	.017	3.2
0.60, API,T39	.022	.015	.016	.021	.072	13.4
0.60, Inc.T36E2	.003*	.018	.010	.011	.041	7.6
20mm, HEI, M97	.005	.019	.030	.007	.060	11.2
20mm, Inc, M96	.003*	.029	.025	.021	.076	14.1
3cm, HE (German)	.010*	.237	.040	.019	.288	53.6
37mm, HE, M54	.174	.082	.050	.033	.303	56.4

Caliber and type of ammunition	Probability that a hit on the plane produces a "B" kill due to Engine $P_{B_{E_{ss}}}$	Structure $P_{B_{S_{ss}}}$	Pilot $P_{B_{P_{ss}}}$	Fuel Tanks $P_{B_{F_{ss}}}$	Overall Prob. $1-\pi_{i=E}^{i=F}(1-P_{B_i}) = P_B$	Lethal Area** (ft^2)
0.50, API-T, M20	.011	.011	.010	.006	.037	6.9
0.60, API, T39	.034	.036	.016	.034	.115	21.4
0.60, Inc, T36E2	.039*	.036	.010	.021	.103	19.2
20mm, HEI, M97	.045	.034	.030	.017	.120	22.3
20mm, Inc, M96	.048*	.041	.025	.035	.141	26.2
30mm, HE (German)	.065*	.333	.040	.038	.424	78.9
37mm, HE,M54	.194	.097	.050	.047	.341	63.4

* Obtained from firings vs B-25 engines

** Lethal area = P_A (or P_B) x projected area of plane (186 sq. ft.)

The overall probabilities are depicted in Figs. 9 and 10.

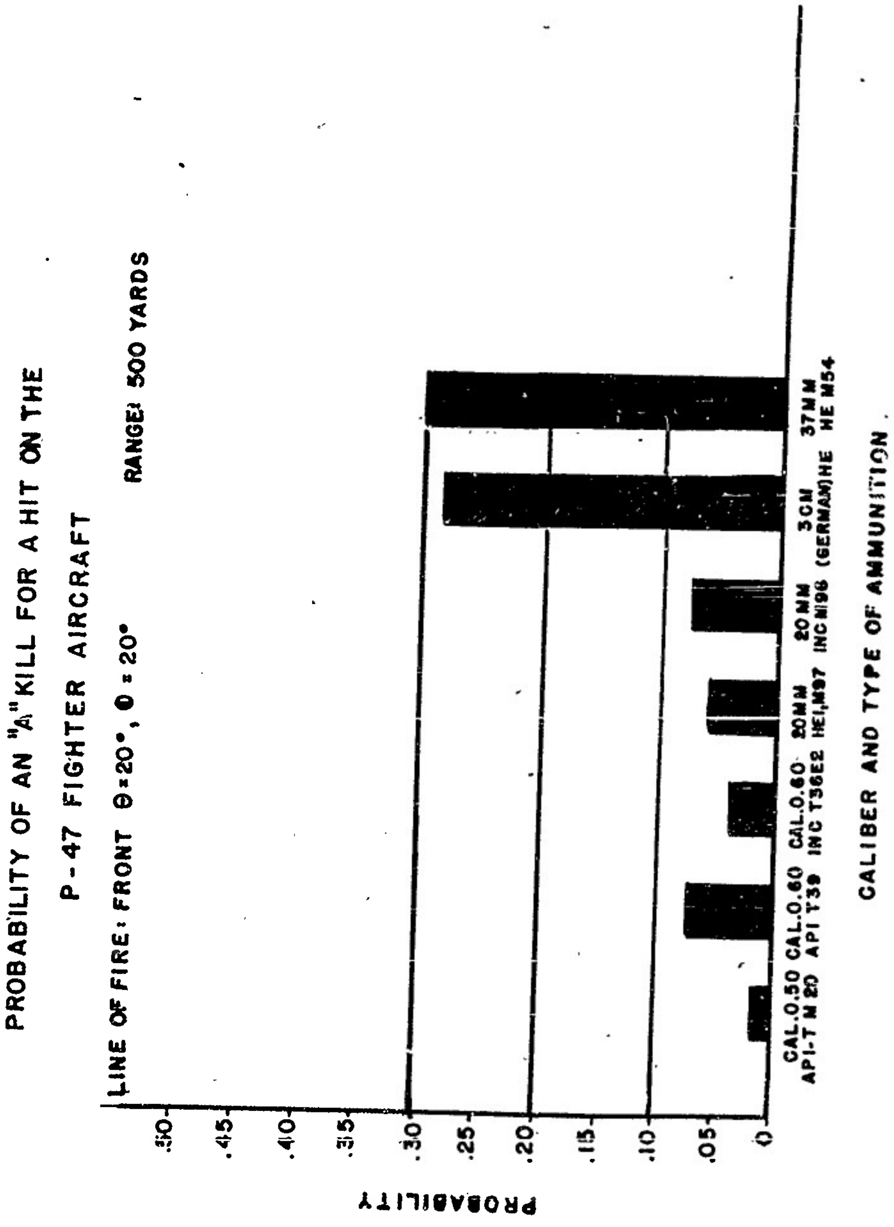


FIG. 9

PROBABILITY OF A "B" KILL FOR A HIT ON THE P-47 FIGHTER AIRCRAFT

FRONT θ = 20°, Φ = 20° RANGE: 500 YARDS

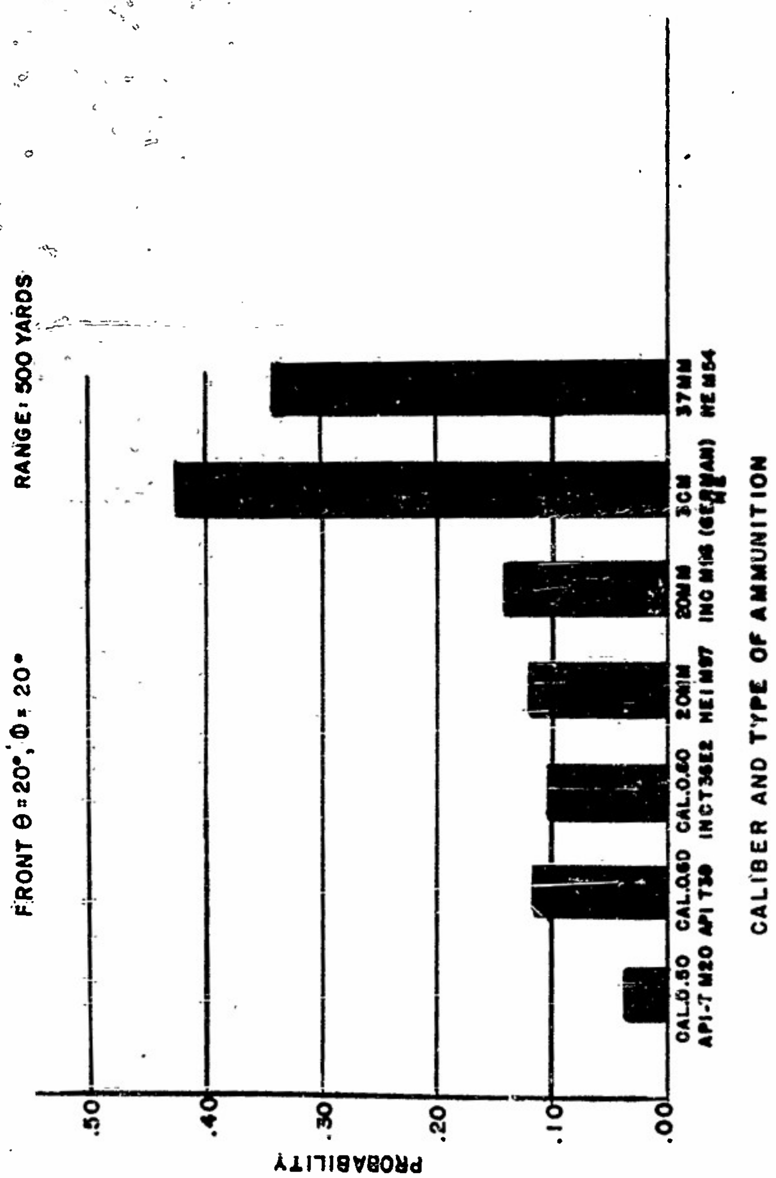


FIG.10

2. Structure. The probability that a hit results in a kill on the P-47 due to structure damage, is designated as $P_{A_{S_{ss}}}$ and $P_{B_{S_{ss}}}$ in Table 3. "Structure" damage here refers to all damage other than that due to the engine and accessories, the pilot or the fuel tanks. It was attempted during firing to obtain as uniform a distribution of impacts over the projected area of the plane as possible. Since in fact the distribution was not ideally uniform, the average damage was obtained for each of many zones into which the total projected area of the plane was divided. These averages were then weighted by the relative projected areas of their respective zones. The final average for structure damage, therefore, does not reflect any bias resulting from disproportionate numbers of impacts on components of varying vulnerability. Since the component termed "structure" includes the entire plane, the projected areas are the same and no further correction is required.[1]

3. Pilot. There is no armor protection for the pilot with the line of fire employed in firing against the P-47. For that reason any hit on the projected area resulted in injury to the dummy target representing the pilot. In addition there is some injury resulting from near misses due to flying glass or fragments. If it is considered that the pilot represents 3 sq. ft. of projected area out of the 186 sq. ft. for the entire plane, then a hit on the plane resulting in a pilot hit was chosen as the probability of a pilot kill for the cal. 0.60 API, T39. The cal. 0.50 and the cal. 0.60 Inc. were given slightly smaller probabilities and the HE rounds were given somewhat larger probabilities in accordance with the relative effect of direct hits and near misses for the various types of ammunition as observed during firings. There were too few impacts for each type of ammunition in the P-47 firings to make a purely objective measure of this type of vulnerability.

4. Fuel Tanks. Since there were, in all, 15 P-47's available for these tests, the plane-consuming fuel tank tests could not be conducted against the P-47 with loaded fuel tanks. The following procedure was therefore adopted to obtain the vulnerability of this important component. Much data was available from firings previously conducted against the loaded fuel cells of 53 A-35 attack bombers. Firings against these fuel cells were conducted from the front and from the rear at the same angle-off as employed in the P-47 firings. It was then assumed that the probability of fire and leakage in the P-47 tanks when hit was the same as for the A-35 tanks when hit. In addition, the probabilities obtained by fire from the front against the A-35 tanks were assigned to those impacts on the projected area of the P-47 tanks which would be less than one foot from the tank itself. The probabilities from rear firing against A-35 tanks were employed for all other P-47 impacts. It was then necessary to obtain the probability that the P-47 tanks would in fact be pierced by bullets or fragments impacting less than one foot and greater than one foot away from the tanks. These probabilities were obtained from the structures phase of the test and also from a thorough series of supplementary firings conducted against expended P-47's. The multiplication of corresponding probabilities than gave the probability of leakage if the projected area of P-47 fuel tanks is hit and also the probability of fire. These were in turn multiplied by the relative projected area of the fuel tanks to that of the entire plane to give the probabilities of fire and of leakage if the plane is hit.

[1] The components are assessed according to their function. Thus it is possible that a hit on a fuel tank may do fuel damage (fire or leakage) and also do independent structural damage to the plane.

The probabilities of obtaining "A" and "B" kills from the fire or leakage were then obtained from the results of firing against the fuselage tanks of the A-35's. In general, the larger calibers gave larger and brisker fires and more pronounced leakage. The seriousness of the fire or leakage is chiefly reflected in the differing "A" assessments since fire or non-self-sealing leakage in the main fuel cell of the P-47 is almost always a 100B kill. Corresponding probabilities were then multiplied to obtain the probabilities of an "A" (or "B") kill if the plane is hit due to fire (or leakage). The probabilities of a kill resulting from fire and from leakage were combined to give the values listed in Table 3.

The limited number of observations available per plane for fuel tank firings makes necessary some system of extrapolation such as that outlined above. Its use is considered valid when only single shot damage is considered, as above. For inclusion of compound damage, however, it is advisable to rely chiefly on results for the same plane as is under consideration. Thus, for the probability of damage from two or more hits on the P-47, the probability of leakage on a first hit may be obtained by some extrapolation but the probability of fire or explosion for a subsequent hit on the fuselage near the fuel tanks is linked too closely with the type of target to be reliably estimated by extrapolation from other types of aircraft. Since no fuel tank firings were conducted against the P-47 itself, it was not considered advisable to calculate compound fuel tank damage for this plane. This is especially necessary since the P-47 fuel tank installation differs radically from those in aircraft used for fuel tank tests.

There is a good possibility that more P-47 type aircraft will be made available in the near future. It will thus be possible to obtain direct information as to pilot and compound fuel vulnerability.

Better estimates of the various component probabilities may be obtained by attention to detailed areas and sub-components. It is hoped to present these values in a later report on the P-47.

The projected areas for the P-47 engine and structure zones were obtained by planimeter readings of these areas on the photograph of a model (see Figure H1, Appendix H). The scale of the model is 1:72. The pictures represent the exposed areas simulating a range of 185 yards. These relative areas differ negligibly from those which would be seen at 500 yards.

Figures 11, 12 and 13 picture the contribution of engine, structure, pilot and fuel vulnerability to the overall vulnerability of the P-47. The scale for these figures may be used to read the total overall vulnerability. These scales are so selected because component vulnerabilities are not additive, although their logarithms are, to obtain overall vulnerability. If one of the components is rendered invulnerable by some protective device, then the block on the charts identified with that component may be removed and the total vulnerability is then the sum of the remaining component damage, added logarithmically. To read the absolute value of a component vulnerability the reader is advised to use Table 3. However, on the charts they may be read by placing the origin on the scale in line with the lower bound of the block identified with the component.

PROBABILITY THAT A HIT ON THE P-47 FIGHTER WILL PRODUCE AN "A" KILL DUE TO:

(F) FUEL
(P) PILOT
(S) STRUCTURE
(E) ENGINE

LINE OF FIRE: FRONT, BELOW. Θ = 20°, Φ = 20°

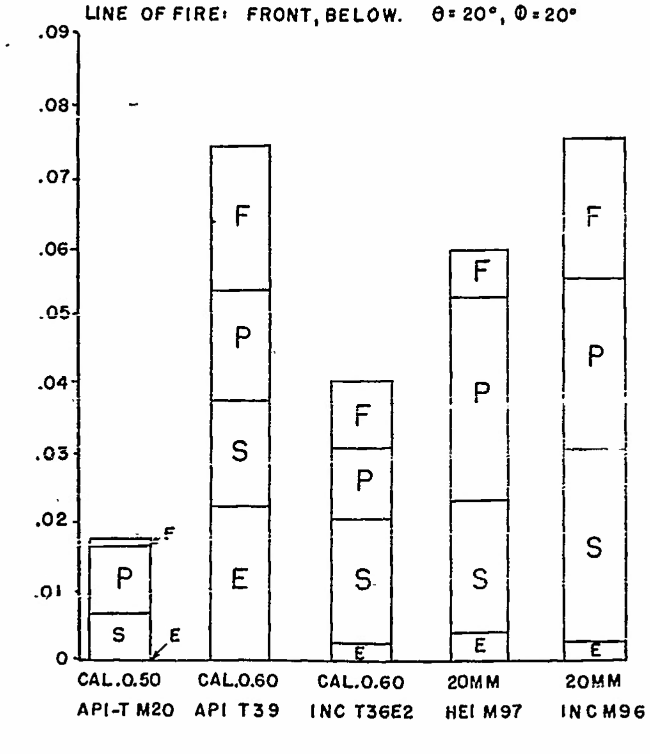


FIG.11

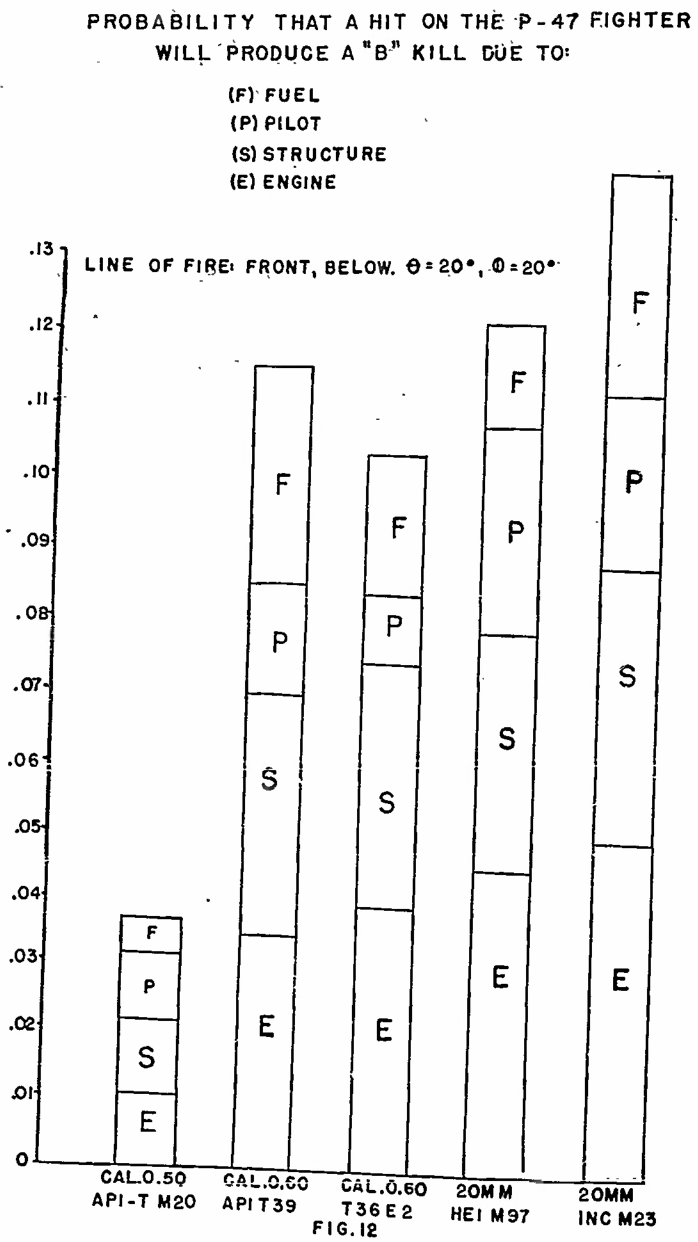

PROBABILITY THAT A HIT ON THE P-47 FIGHTER WILL PRODUCE A "B" KILL DUE TO:
(F) FUEL
(P) PILOT
(S) STRUCTURE
(E) ENGINE
LINE OF FIRE: FRONT, BELOW. θ=20°, Φ=20°
CAL.0.50 API-T M20
CAL.0.60 API T39
CAL.0.60 T36 E2
20MM HEI M97
20MM INC M23

FIG. 12

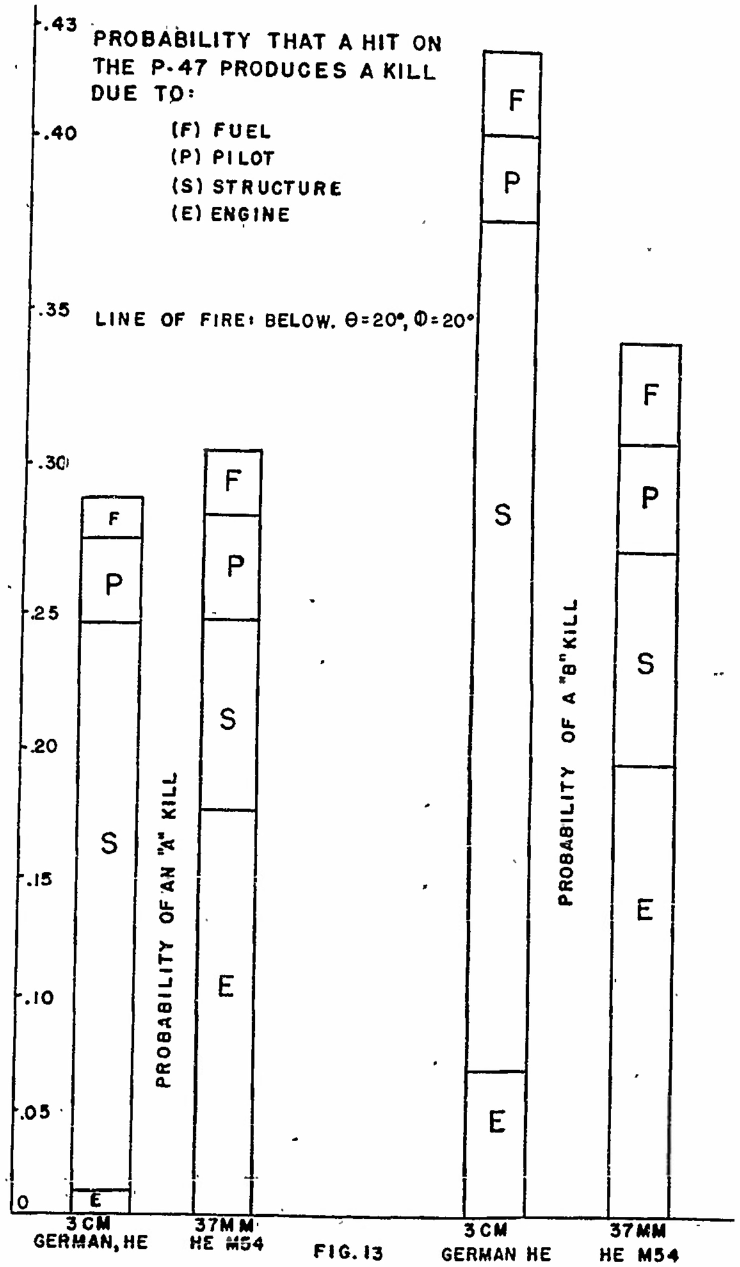

PROBABILITY THAT A HIT ON THE P-47 PRODUCES A KILL DUE TO:
(F) FUEL
(P) PILOT
(S) STRUCTURE
(E) ENGINE
LINE OF FIRE: BELOW. θ=20°, Φ=20°
PROBABILITY OF AN "A" KILL
PROBABILITY OF A "B" KILL
3 CM GERMAN, HE
37MM HE M54
3 CM GERMAN HE
37MM HE M54

FIG. 13

PROBABILITY THAT A HIT ON THE B-25 PRODUCES A KILL

The probability that one hit at random on the B-25 produces an "A" or "B" kill with any type of ammunition was obtained for firing against the bomber from the rear and above ($\theta = 20°$, $\phi = 13°$) and for a range of 500 yards. This probability is based on results obtained with the B-25 itself and also the fuel tank damage obtained with other aircraft types.

Table 4 lists the contribution of the major aircraft components to the overall probability that a hit on the B-25 bomber produces an "A" or "B" kill. The table presents the probabilities that one hit at random on the B-25 will produce a kill due to engine, structure, pilot or fuel tank damage. The B-25, unlike the P-47, has major components which are doubly vulnerable. That is to say, there exist duplicated components, both of which must be killed in order to obtain a kill on the plane. In particular, the engines and pilots are major components which are doubly vulnerable. Consequently, they contribute nothing to the overall probability of a kill on the B-25 for just one hit. These components, however, are important sources of vulnerability for many hits on the B-25 and their contribution to the overall vulnerability is presented in the next section. Figures 14 and 15 picture the probabilities of "A" and "B" kills for one hit on the B-25.

The various component probabilities listed in Table 4 were obtained as follows:

1. Engines and Pilots. These components are doubly vulnerable and hence contribute nothing to overall vulnerability for one hit on the plane. The German 3cm and the 37mm have about one chance in a thousand of getting both pilots with one hit.

2. Structure. The probability that a hit results in a kill on the B-25 due to structure damage is designated as $P_{A_{S_{ss}}}$ and $P_{B_{S_{ss}}}$ in Table 4. The probability of obtaining such damage to the B-25 is obtained similarly to the P-47, described above.

3. Fuel Tanks. Since the available B-25 aircraft are employed to obtain the B-25 engine and structure damage, they could not also be used for sufficient fuel tank firings. The vulnerability of this component for one hit on the plane was obtained as follows. The few firings against B-25 fuel tanks (see Table E1) were used primarily to obtain overall "A" and "B" assessments for those hits on the B-25 fuel tanks which cause fires. However, more data are required to obtain the probability of obtaining fires for hits on these fuel tanks. This additional information is obtained from the P-38 and A-35 fuel tank firings. The average probability of obtaining a fire for a hit on the projected area of a fuel cell is obtained from the totaled information for A-35, P-38 and B-25 firings against gasoline. The results for firings from the rear and above are obtained from Table E1. This probability is then multiplied by the relative area of the fully loaded fuel cells to the total projected area of the B-25. The product is the probability that a hit on the B-25 will produce a fuel tank fire. It is obtained for two assumptions: 1) only the main cells are fully (the auxiliary tanks empty) and 2) all the cells full. The relative areas for these two cases are respectively .149 and .272. The probability that a hit on the B-25 will produce a fuel tank fire is then multiplied by the average "A" and "B" assessments obtained for the B-25 fuel tank fires to obtain the probability that a hit on the B-25 will be an "A" or "B" kill due to fuel fire. These are the values tabulated as $P_{A_{F_{ss}}}$ and $P_{B_{F_{ss}}}$ in Table 4.

TABLE 4 _ Calculations of the Overall Probability that a Hit on B-25 Produces a Kill

Line of Fire: Rear Above $\theta = 20°$, $\phi = 13°$ Range: 500 yds.

Caliber and Type of Ammunition	Prob. that a hit on the plane produces an "A" Kill due to - Main Fuel Cells Full $P_{A_{F_{ss}}}$	All Fuel Cells Full $P_{A_{F_{ss}}}$	Both Engines $P_{A_{E_{ss}}}$	Structure $P_{A_{S_{ss}}}$	Pilots $P_{A_{P_{ss}}}$	Overall Probability $1 - \prod_{i=F_{ss}}^{i=P_{ss}}(1 - P_{A_i})$ Main Fuel Cells Full P_{A_1}	All Fuel Cells Full P_{A_2}	Lethal Area* (FT^2) Main Fuel Cells Full 1	All Fuel Cells Full 2
Cal. .50 API-T, M20	.000	.000	.000	.000	.000	.000	.000	.000	.000
Cal. .60 API, T39	.004	.007	.000	.001	.000	.004	.008	1.024	2.048
Cal. .60 Inc T36E2	.005	.009	.000	.000	.000	.005	.010	1.280	2.560
20 mm HEI M97	.000	.000	.000	.005	.000	.005	.005	1.280	1.280
20mm Inc M96	.000	.000	.000	.006	.000	.006	.006	1.536	1.536
3cm(Ger) HE	.047	.087	.000	.029	.001	.062	.101	15.872	25.856
37mm HE, M54	.063	.116	.000	.017	.001	.081	.133	20.736	34.048

Caliber and Type of Ammunition	Prob. that a hit on the plane produces a "B" Kill due to - Main Fuel Cells Full $P_{B_{F_{ss}}}$	All Fuel Cells Full $P_{B_{F_{ss}}}$	Both Engines $P_{B_{E_{ss}}}$	Structure $P_{B_{S_{ss}}}$	Pilots $P_{B_{P_{ss}}}$	Overall Probability $1 - \prod_{i=F_{ss}}^{i=P_{ss}}(1 - P_{B_i})$ Main Fuel Cells Full P_{B_1}	All Fuel Cells Full P_{B_2}	Lethal Area* (FT^2) Main Fuel Cells Full 1	All Fuel Cells Full 2
Cal. .50 API-T, M20	.005	.010	.000	.000	.000	.005	.010	1.280	2.560
Cal. .60 API, T39	.013	.024	.000	.003	.000	.016	.027	4.096	6.912
Cal. .60 Inc T36E2	.025	.046	.000	.009	.000	.034	.054	8.704	13.824
20mm HEI, M97	.024	.043	.000	.010	.000	.034	.053	8.704	13.568
20mm, Inc, M96	.015	.028	.000	.020	.000	.035	.047	8.960	12.032
3cm (Ger.) HE	.057	.104	.000	.064	.001	.117	.161	29.952	41.216
37mm, HE, M54	.063	.116	.000	.059	.001	.120	.170	30.720	43.520

* Lethal Area = P_A (or P_B) x projected area of plane (256 sq. ft.)

A similar procedure could be followed for leakage damage for one hit. However, since the leakage produced by one hit is assessed as zero "A" and "B" damage, this is not necessary. The probability of obtaining a kill due to fire for more than one hit on the plane is discussed in the next section.

The relative areas of the various zones and major components for the B-25 were obtained from photographs of a model with scale 1:72. These photographs simulate a range of 185 yards. The relative areas were obtained by planimeter. The model photographs and the tabulated relative areas are presented in Appendix H.

Figures 14 and 15 picture the probabilities of obtaining an "A" or "B" kill respectively for a hit at random on the B-25 bomber. The probabilities are computed for terminal ballistic damage for rounds fired on the ground at a range of 500 yards. The line of fire is from the rear and above, $\theta = 20°$ and $\phi = 13°$. In obtaining the overall figures it was assumed that both engines must be killed for an engine kill and that both pilots must be killed for a kill due to personnel. The main fuel cells are assumed full and the auxiliary cells empty. Since the engines and pilots are doubly vulnerable components, their vulnerability contributed nothing to the vulnerabilities shown in these figures.

PROBABILITY THAT "n" HITS ON THE P-47 PRODUCES A KILL

The contributions of the major components to P-47 vulnerability for one hit were listed in Table 3. Let $P_{A_{E_{SS}}}$, $P_{A_{S_{SS}}}$, $P_{A_{F_{SS}}}$, $P_{A_{P_{SS}}}$ represent the single shot probabilities of a kill on the P-47 due to engines, structures, fuel and personnel respectively. If $P_A^{(n)}$ represents the probability of an "A" kill in "n" hits on the P-47, then

$$P_A^{(n)} = 1 - \prod_{i = E_{SS}}^{i = P_{SS}} (1 - P_{A_i})^n .$$

This formula will give $P_A^{(n)}$ for the P-47, assuming no compounding of damage to the plane in the "n" hits. It is assumed here that hits are independent.

PROBABILITY THAT "n" HITS ON THE B-25 PRODUCES A KILL

The calculation of $P_A^{(n)}$ (or $P_B^{(n)}$), the probability that "n" hits on the B-25 produces an "A" (or a "B") kill will be illustrated below. This calculation will require the killing of both engines for an engine kill, killing both pilots for a personnel kill, and will take account of the greater probability of a fire when a previous hit on a fuel tank produces leakage.

If $P_{A_E}^{(n)}$ represents the probability of a kill in "n" hits due to engine damage, then $1 - P_{A_E}^{(n)}$ is the survival probability for this component for "n" hits. Similar survival probabilities may be obtained for the other components. The product of survival probabilities for all the components is the survival probability for the plane in "n" hits and the complement of this product is the probability of at least one kill on the plane

PROBABILITY OF AN "A" KILL FOR A HIT ON THE B-25 BOMBER AIRCRAFT

LINE OF FIRE: REAR, ABOVE. $\theta = 20°$, $\phi = 13°$ RANGE: 500 YARDS

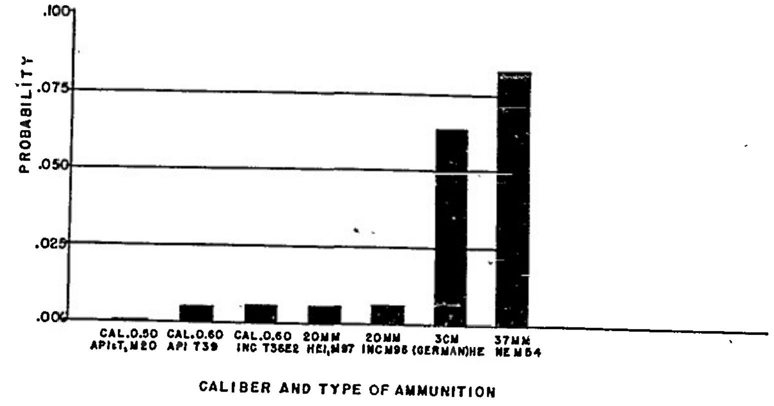


FIG. 14

PROBABILITY OF A "B" KILL FOR A HIT ON THE B-25 BOMBER AIRCRAFT

LINE OF FIRE: REAR, ABOVE. $\theta = 20°$, $\phi = 13°$ RANGE: 500 YARDS

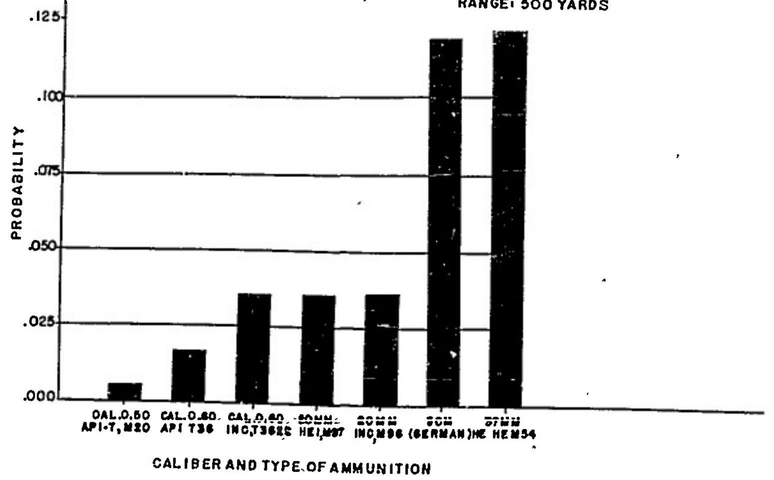


FIG. 15

in "n" hits. The procedures outlined below indicate the methods used to obtain the survival probabilities for the various major components of the B-25.

1. Engine Survival Probability for "n" Hits.

In Table C6 is listed, for each type of ammunition, the probability that a hit on the B-25 engine from the rear and above results in an "A" or "B" kill. The relative area of each nacelle is about .035. Then .035 multiplied by the probabilities from Table C6 gives the probability that a hit on the B-25 will kill one of the engines. Call this product $P_{A_{E_1}}^{(1)}$. Then $(1-P_{A_{E_1}}^{(1)})^n$ is the probability that one of the engines will survive "n" hits on the plane. For small probabilities a simple approximation may be obtained.

Then

$$1-\left[1-(1-P_{A_{E_1}}^{(1)})^n\right]^2 = 1-P_{A_E}^{(n)}$$

is the probability that both engines will not be simultaneously killed in "n" hits on the plane. $P_{A_E}^{(n)}$ is the probability that they will be killed. It is assumed here that compound engine damage from several hits is not more than one would expect from the single-shot results. Firing tests thus far support this assumption.

2. Personnel Survival Probability for "n" Hits.

Pilot personnel on the B-25 constitute a doubly vulnerable component similar to the engine. The calculation of the personnel survival probability for "n" hits on the B-25 is similar to that for engines.

3. Structures Survival Probability for "n" Hits.

The structures survival probability for "n" hits on the B-25 may be calculated in a similar manner as for the P-47. Table F3 gives the overall probability of the structures kill in one hit on the B-25. Call this probability $P_{A_S}^{(1)}$. Then $(1-P_{A_S}^{(1)})^n$ is the structures survival probability for "n" hits.

4. Fuel Tank Survival Probability for "n" Hits.

Let p_{NM}, p_{FM}, p_{NA}, and p_{FA} be the relative areas of the near main fuel cells, the far main fuel cells, the near auxiliary cells and the far auxiliary cells in the B-25 from the rear, above with $\theta = 20°$, $\phi = 13°$. These relative areas are .078, .071, .063 and .060 respectively.

Table E1 lists the probability of a fire for penetration of a fuel cell obtained by totaling results from the rear and above for the A-35, P-38 and B-25 firings. From this table one can also obtain the probability that a hit on the projected area of a B-25 fuel cell will actually penetrate the cell. Full and empty cell results are pooled to get this probability of penetration. The product of the probability of a fire for cell penetration by the probability of penetration for a hit on the projected area of the cell, is $P_{F_{ss}}$, the single-shot probability of a fire for a hit on the B-25 cell. $A_{F_{ss}}$, $B_{F_{ss}}$, A_{F_c} and B_{F_c} are the average "A" and "B" assessments of B-25 single-shot and compound fires. These values are given for the various types of ammunition in Tables E1 and E2. Then the probability for an "A" kill due to single-shot fire in one hit on the B-25 with the main cells full is $P_{A_{F_{ss}}}^{(1)} = (A_{F_{ss}})(P_{F_{ss}})(p_{NM}+p_{FM})$.

The probability of an "A" kill due to single-shot fuel damage in "n" hits is

$$P'^{(n)}_{A_{F_{ss}}} = 1-\left(1-P^{(1)}_{A_{F_{ss}}}\right)^n$$

The probability of survival is here $1-P^{(n)}_{A_{F_{ss}}}$.

In a similar manner the survival probabilities may be obtained for "B" single-shot fuel kills and for the assumption that all the fuel cells are full.

There is, however, additional source of fuel tank fire damage due to the additional probability that a round may cause a fire when a previous round impacting in the same area has caused leakage. This case is especially important when there is more than one burst at the target. The formula for calculating the additional probability of a compound fire is developed in Appendix B of BRL M437.

Let P_{F_c} be the compound probability of a fire for a hit on a leaking cell. P_{F_c} may be determined similarly to $P_{F_{ss}}$ by the use of Table E2. Let $P_{F_{\Delta c}} = P_{F_c} - P_{F_{ss}}$ be the additional probability of a fire due to previous leakage and $P_{L_{ss}}$ be the probability of leakage and no fire for a single-shot hit on a B-25 fuel cell. Then

$$P_{F_m} = 1 + \frac{P_{F_{\Delta c}}(1-P_{L_{ss}})^m - P_{L_{ss}}(1-P_{F_{\Delta c}})^m}{P_{L_{ss}} - P_{F_{\Delta c}}}$$

is the probability of getting at least one fire due to compounding if the cell is hit "m" times. Now the probability of getting "m" hits on the cell out of "n" rounds is calculated separately for each fuel tank area. Thus, for the near main cell, this probability is

$$\frac{e^{-np_{NM}}(np_{NM})^m}{m!}$$, using the Poisson approximation to the binomial.

Then for any one area, say for the near main cell, the probability of fire, due to compounding, for "n" hits on the plane is

$$P^{(n)}_{CF} = \sum_{m=0}^{m=n} \frac{e^{-np_{NM}}(np_{NM})^m P_{F_m}}{m!}$$

Then $P^{(n)}_{A_{F_c}}(NM) = A_{F_c} P^{(n)}_{CF}$ is the probability that "n" hits on the plane will result in an "A" kill due to the additional probability of compound fires in the near main cell. If the far main cell is the only other cell containing fuel when the plane is over the target, then

$$P'^{(n)}_{A_F} = 1 - \left(1-P'^{(n)}_{A_{F_{ss}}}\right)\left(1-P^{(n)}_{A_{F_c}}(NM)\right)\left(1-P^{(n)}_{A_{F_c}}(FM)\right)$$

is the total probability of an "A" kill due to fuel tank fires in "n" hits on the B-25, including both single-shot and compound fires.

Table 5 is presented to illustrate the effect of including the estimates of compound fuel damage in evaluating the overall vulnerability of the B-25 fuel tank fire damage in "n" hits.

Figures 16 and 17 depict the probabilities of obtaining an "A" or "B" kill respectively for 10 random hits on the B-25. The line of fire considered is from the rear and above with $\theta = 20°$ and $\phi = 13°$. All hits are assumed delivered with a striking velocity equivalent to that obtained from a range of 500 yards at sea level. Three cases are pictured for B-25 vulnerability. The first considers the main fuel tanks fully loaded (auxiliary tanks empty) and includes compound fires. This is the same case as depicted for one hit in figures 14 and 15. The second case also considers the main fuel tanks fully loaded but only involves single shot fuel tank damage. The difference in these two cases is the effect of cumulative fuel tank damage on overall vulnerability. From a consideration of the data accumulated to date, therefore, there would seem to be but little difference in overall aircraft vulnerability for varying time intervals between impacts. If this is so, then from a terminal ballistic standpoint, the vulnerability of the target under repeated passes would be little different from that for one long burst. It was noted in the previous section of this report that the major components of the target airplane display different vulnerabilities for different lines of fire. The line of fire from the rear and above against the B-25, for which overall probabilities are presented in this section, is one for which the B-25 is relatively invulnerable. Calculations are now being made of the overall vulnerability of this plane for other angles of fire. For this reason, the figures given in this portion of the report, and the overall computations of part III must be considered as indicative of results only from the angles considered and not as suitable for overall comparisons of the weapons and ammunition.

Figures 18, 19 and 20 picture the contributions of engine, structure, pilot and fuel vulnerability to the overall vulnerability of the B-25 for 10 random hits. These figures are to be interpreted similarly to figures 11, 12 and 13 presented for the P-47.

Figures 21 and 22 compare the vulnerabilities of the P-47 and B-25 to 10 random hits for the specified angles of fire. It should be recalled that the P-47 engine and pilot are singly vulnerable. Part III of this report supplies a comparison of the effectiveness of various types of ammunitions against these two planes, taking into account the fact that the B-25 is almost three times as easy to hit as the P-47 as well as the weight, rates of fire and other characteristics of the weapons.

Figures 23 and 24 compare the probabilities of obtaining "A" and "B" kills for the various calibers for "N" hits on the P-47 from the front and below, delivered from a range of 500 yards. Figures 25 and 26 do this for the B-25, with fire from the rear and above.

Figures 27 - 33 present, for each caliber, the probabilities of an "A" or "B" kill in "N" hits on the B-25 for three different assumptions, viz 1) main tanks fully loaded, including compound fires and both engines disabled for a kill, 2) main fuel tanks fully loaded, including compound fires and only one engine disabled for a kill and 3) all fuel tanks fully loaded, single shot fire damage only, and both engines disabled for

TABLE 5

Comparison of Single and Compound Fuel Damage for "n" Hits on the B-25

Ammunition	Hits	Total Probability of Killing due to Compound Fire in "n" Hits: All cells full $P'_{A_{F_c}}$	All cells full $P'_{B_{F_c}}$	Main cells full $P''_{A_{F_c}}$	Main cells full $P''_{B_{F_c}}$	Probability of Killing Plane due to Single Shot Fire in "n" Hits: All cells full $P'_{A_{F_{ss}}}$	All cells full $P'_{B_{F_{ss}}}$	Main cells full $P''_{A_{F_{ss}}}$	Main cells full $P''_{B_{F_{ss}}}$
Cal. .50 API-T, M20	1	[illegible]	[illegible]	.000	[illegible]	.000	.010	.000	.005
	2	.000	.021	.000	.012	.000	.020	.000	.011
	4	.001	.044	.001	.025	.000	.039	.000	.022
	6	.002	.070	.001	.039	.000	.058	.000	.032
	8	.003	.096	.002	.055	.000	.077	.000	.043
	10	.005	.125	.003	.071	.000	.095	.000	.053
	20	.019	.276	.011	.167	.000	.182	.000	.104
Cal. .60 API, T39	1	.007	.024	.004	.013	.007	.024	.004	.013
	2	.015	.051	.008	.028	.014	.048	.008	.026
	4	.031	.105	.017	.059	.029	.094	.016	.052
	6	.050	.162	.026	.093	.043	.138	.023	.077
	8	.064	.221	.036	.128	.056	.179	.031	.102
	10	.081	.277	.046	.164	.070	.219	.039	.125
Cal. .60 Inc. T36E2	1	.009	.046	.005	.025	.009	.046	.005	.025
	2	.019	.092	.013	.051	.018	.090	.012	.050
	4	.038	.179	.021	.102	.037	.172	.020	.097
	6	.058	.262	.032	.152	.054	.246	.030	.142
	8	.076	.338	.043	.201	.072	.314	.039	.185
	10	.097	.411	.054	.252	.089	.375	.049	.225
20mm Inc. M96	1	.000	.028	.000	.015	.000	.028	.000	.015
	2	.001	.055	.000	.031	.000	.054	.000	.030
	4	.002	.108	.001	.059	.000	.106	.000	.058
	6	.004	.159	.002	.088	.000	.154	.000	.085
	8	.007	.208	.004	.116	.000	.200	.000	.112
	10	.011	.257	.006	.144	.000	.244	.000	.137
20mm, HEI, M97	1	.000	.044	.000	.024	.000	.044	.000	.024
	2	.002	.088	.001	.049	.000	.086	.000	.048
	4	.006	.171	.002	.097	.000	.165	.000	.093
	6	.011	.249	.007	.145	.000	.237	.000	.136
	8	.020	.323	.012	.192	.000	.302	.000	.177
	10	.030	.391	.018	.237	.000	.362	.000	.216
3cm, (German), HE, MK108	1	.086	.103	.047	.056	.086	.103	.047	.056
	2	.165	.196	.092	.109	.165	.196	.092	.109
	4	.303	.354	.176	.206	.302	.353	.175	.206
	6	.418	.481	.253	.293	.417	.480	.251	.292
	8	.515	.583	.321	.371	.513	.582	.320	.369
	10	.595	.666	.395	.440	.593	.664	.382	.438
37mm, HE. M54	1	.116	.116	.063	.063	.116	.116	.063	.063
	2	.218	.218	.123	.123	.219	.219	.123	.123
	4	.301	.301	.232	.232	.389	.389	.231	.231
	6	.526	.526	.328	.328	.523	.523	.325	.325
	8	.632	.632	.413	.413	.627	.627	.408	.408
	10	.714	.714	.487	.487	.709	.709	.481	.481

PROBABILITY OF AN "A" KILL FOR 10 RANDOM HITS ON THE B-25 BOMBER
LINE OF FIRE: REAR, ABOVE. θ=20°, Φ=13° RANGE: 500 YARDS

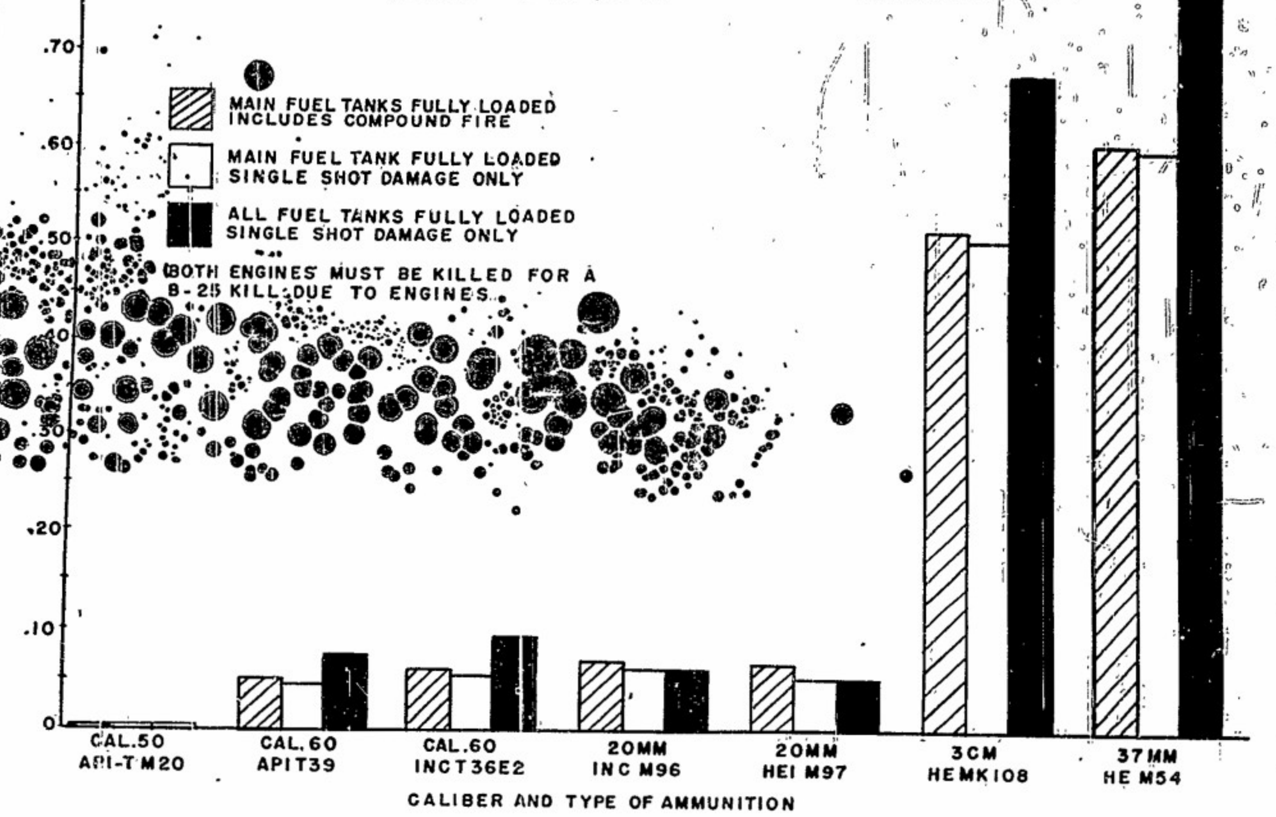


FIG. 16

PROBABILITY OF A "B" KILL FOR 10 RANDOM HITS ON THE B-25 BOMBER
LINE OF FIRE: REAR, ABOVE. θ = 20°, Φ = 13° RANGE: 500 YARDS

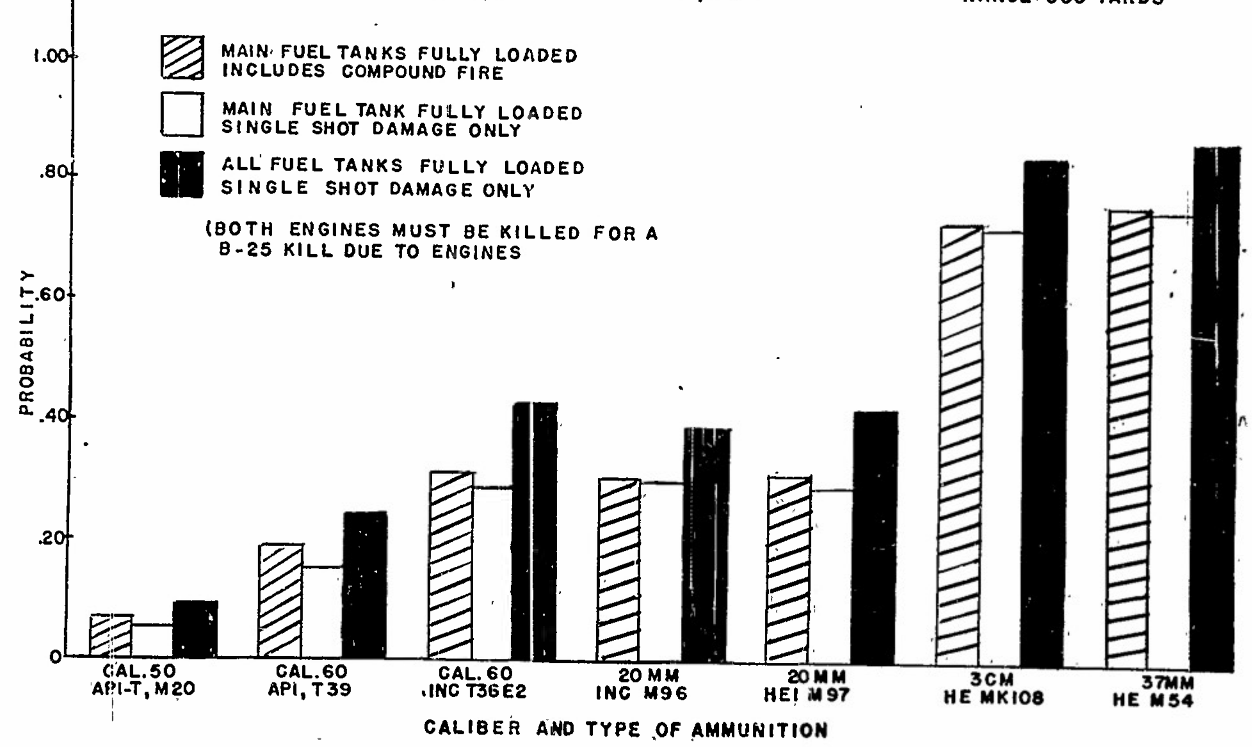


FIG. 17

PROBABILITY THAT 10 RANDOM HITS ON THE B-25 BOMBER WILL PRODUCE AN "A" KILL DUE TO:

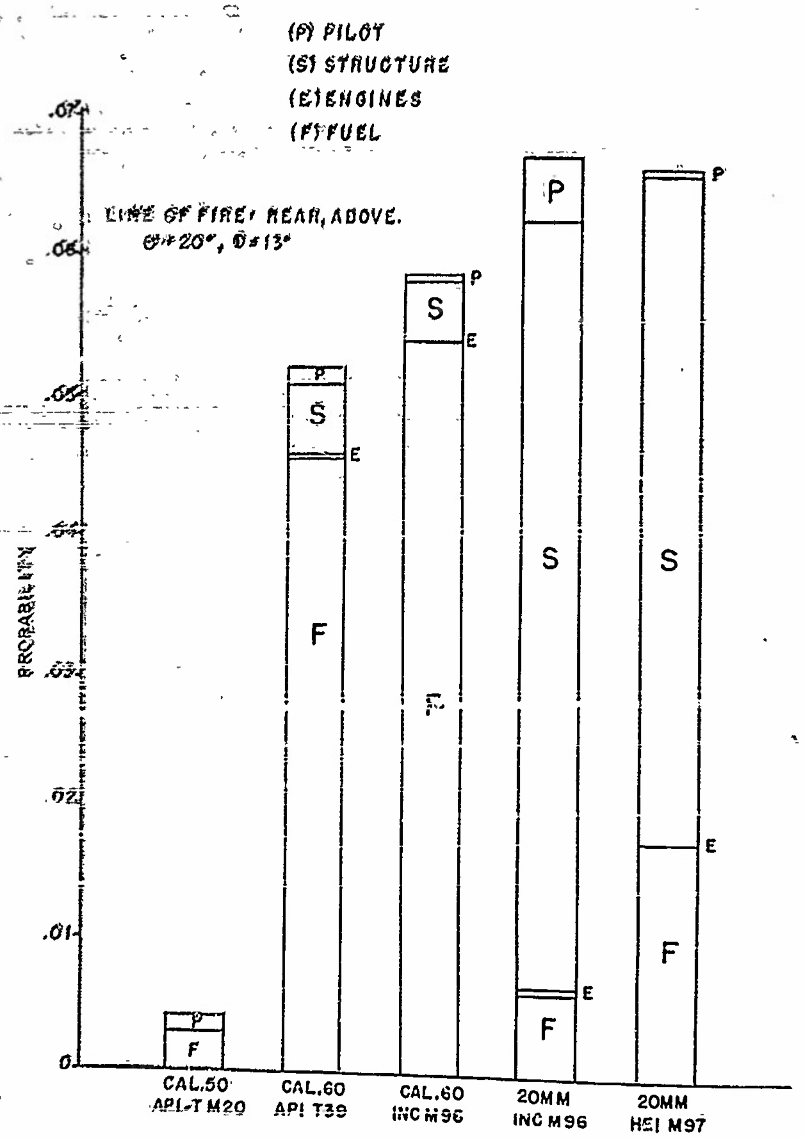


FIG. 18

PROBABILITY THAT 10 RANDOM HITS ON THE B-25 BOMBER WILL PRODUCE A "B" KILL DUE TO:

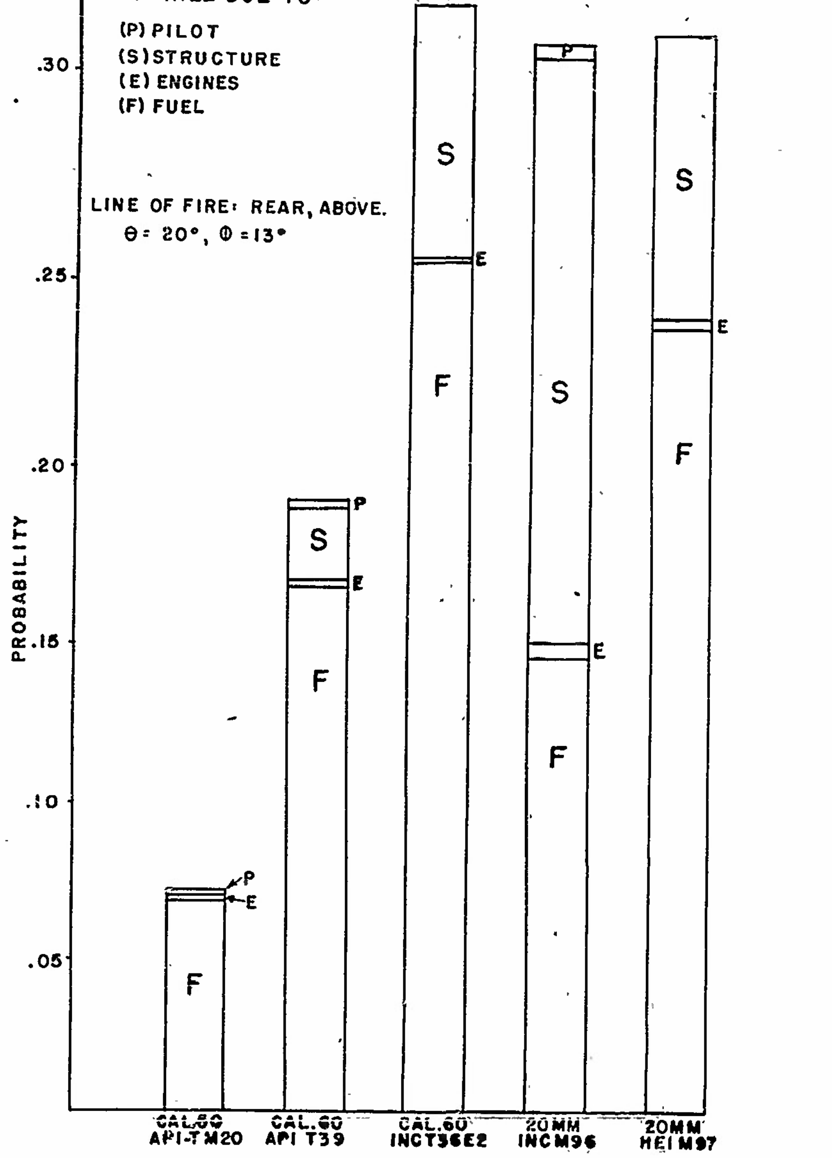


FIG. 19

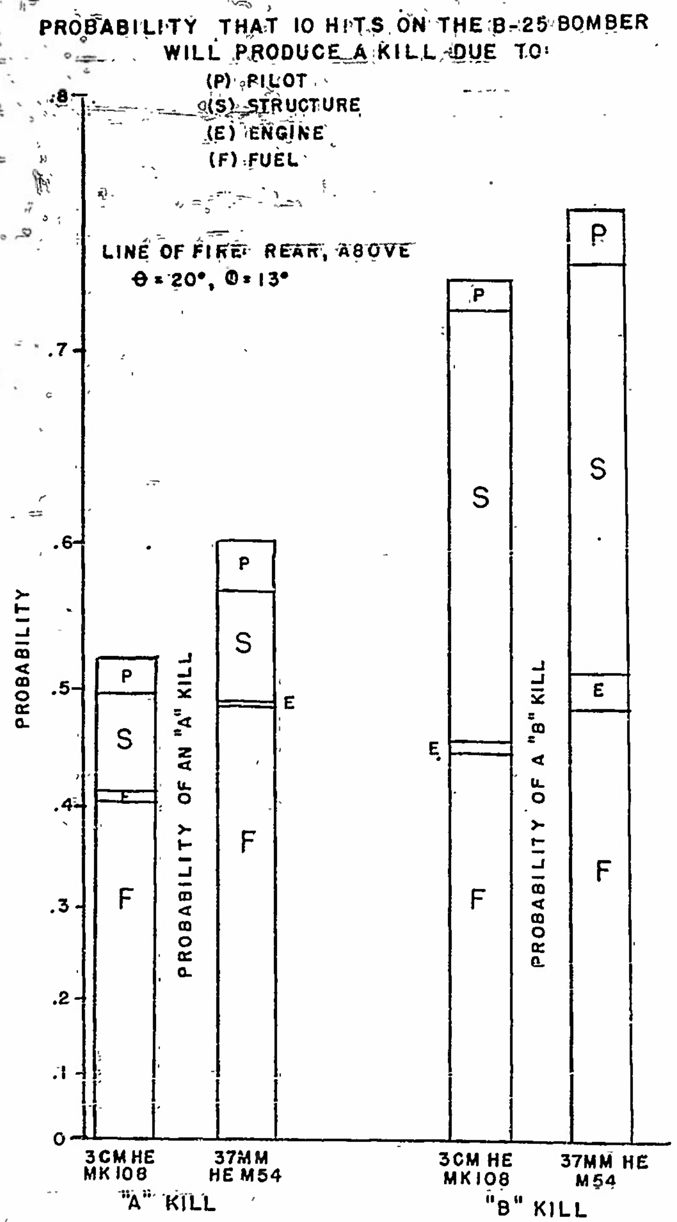


FIG. 20

a kill. It will be noted that for the cal. 0.50 and 20mm where fires were not sufficiently severe to warrant "A" assessment the comparison of assumptions 1) and 3) only reflect differences in vulnerabilities with and without compounding of fires. The greater area for "all tanks fully loaded" is not then reflected in increased "A" damage. However, all calibers were capable of causing fuel fires with some assessable "B" damage. Therefore, for "B" damage the increase in area for "all tanks fully loaded" is significant and outweighs the difference between single-shot and compound fires.

Table 6 presents the estimates of component vulnerabilities for one hit on the B-25. This table is used in Part III for the evaluation of overall armament effectiveness. The component probabilities which are listed assume the engines and pilots to be singly vulnerable. Under the assumption, the total probability

TABLE 6

Component Probabilities for One Hit at Random on the B-25
for Singly Vulnerable Components

Line of Fire: Rear, Above θ = 20°, ∅ = 13° Range: 500 yards

Ammunition	Probability of an "A" Kill to B-25 in one Hit						
	Due to single-shot fire, main cells full P_{A_F}(B-25)	Due to kill on spec. one of the two engines $P_{A_{E_1}}$(B-25)	Due to kill on spec. one of the two pilots $P_{A_{P_1}}$(B-25)	Due to kill on structures P_{A_S}(B-25)	$P_{A_F} + 2P_{A_{E_1}} + 2P_{A_{P_1}} + P_{A_S} = P_A$(B-25)	$\frac{P_{A_{P_1}}}{P_A}$	$\frac{P_{A_{E_1}}}{P_A}$
Cal. 0.50, API-T M20	.000	.000	.005	.000	.010*	.455*	.050*
Cal. 0.60, API, T39	.004	.002	.006	.001	.021	.308	.085
Cal. 0.60 Inc, T36E2	.005	.001	.003	.000	.013	.214	.076
20 MM, Inc, M96	.000	.002	.008	.006	.028	.302	.074
20 MM, HEI, M97	.000	.001	.002	.005	.012	.209	.073
3cm, (German), HE	.047	.014	.024	.015	.139	.173	.103
37 MM, HE, M54	.063	.005	.031	.017	.152	.204	.030

Ammunition	Probability of a "B" Kill to B-25 in one Hit						
	P_{B_F}(B-25)	$P_{B_{E_1}}$(B-25)	$P_{B_{P_1}}$(B-25)	P_{B_S}(B-25)	P_B(B-25)	$\frac{P_{B_{P_1}}}{P_B}$	$\frac{P_{B_{E_1}}}{P_B}$
Cal. 0.50, API-T M20	.005	.002	.005	.000	.018	.250	.114
Cal. 0.60, API T39	.013	.005	.006	.003	.039	.168	.129
Cal. 0.60, Inc, T36E2	.025	.004	.003	.009	.046	.060	.077
20MM, Inc, M96	.015	.008	.008	.020	.067	.126	.112
20MM, HEI, M97	.022	.006	.002	.010	.048	.050	.120
3cm, (German), HE	.057	.015	.024	.064	.199	.121	.076
37MM, HE, M54	.063	.031	.031	.059	.246	.126	.125

* Calculations based on terms with more than the three decimal places printed above.

of getting a kill due to engines for one hit on the B-25 would be $2\,P_{A_{E_1}}$. Similarly the total probability of getting a kill due to personnel for one hit on the B-25 would be $2\,P_{A_{P_1}}$. The probability of a kill for one hit on the B-25 considering all components singly vulnerable is $P_A = P_{A_F} + 2\,P_{A_{E_1}} + 2\,P_{A_{P_1}} + P_{A_S}$. The last two columns in the table present the fractions of the total vulnerability assignable to one of the engines or one of the pilots, and are used in correcting the "singly vulnerable" figures to proper consideration of vulnerability with duplicated components.

The overall vulnerabilities of the P-47 fighter and the B-25 bomber to "n" random hits have been presented. It is to be noted that these figures pertain to a particular range and line of fire in each case. For the P-47 the vulnerabilities are presented for fire from the front, $\Theta = 20°$, $\phi = 20°$, delivered from a range of 500 yards on the ground. For the B-25 the vulnerabilities are presented for fire from the rear and above, $\Theta = 20°$, $\phi = 13°$, also for a range of 500 yards on the ground. The results of firings against components, presented in Part I, indicate large changes in vulnerability with orientation. Firings now in progress at ranges of 1000 yards show that the relative decrease in vulnerability for lower striking velocities is not the same for all the calibers. For these reasons, it is expected that the relative vulnerabilities of these aircraft will be sufficiently different at the angles and ranges to hinder extensive generalizations at this time. Data obtained since 1 December 1946 are now being reduced for addition to the results presented in this report. It is hoped to incorporate these results in a later report, with detailed description of the reliability of the vulnerability estimated.

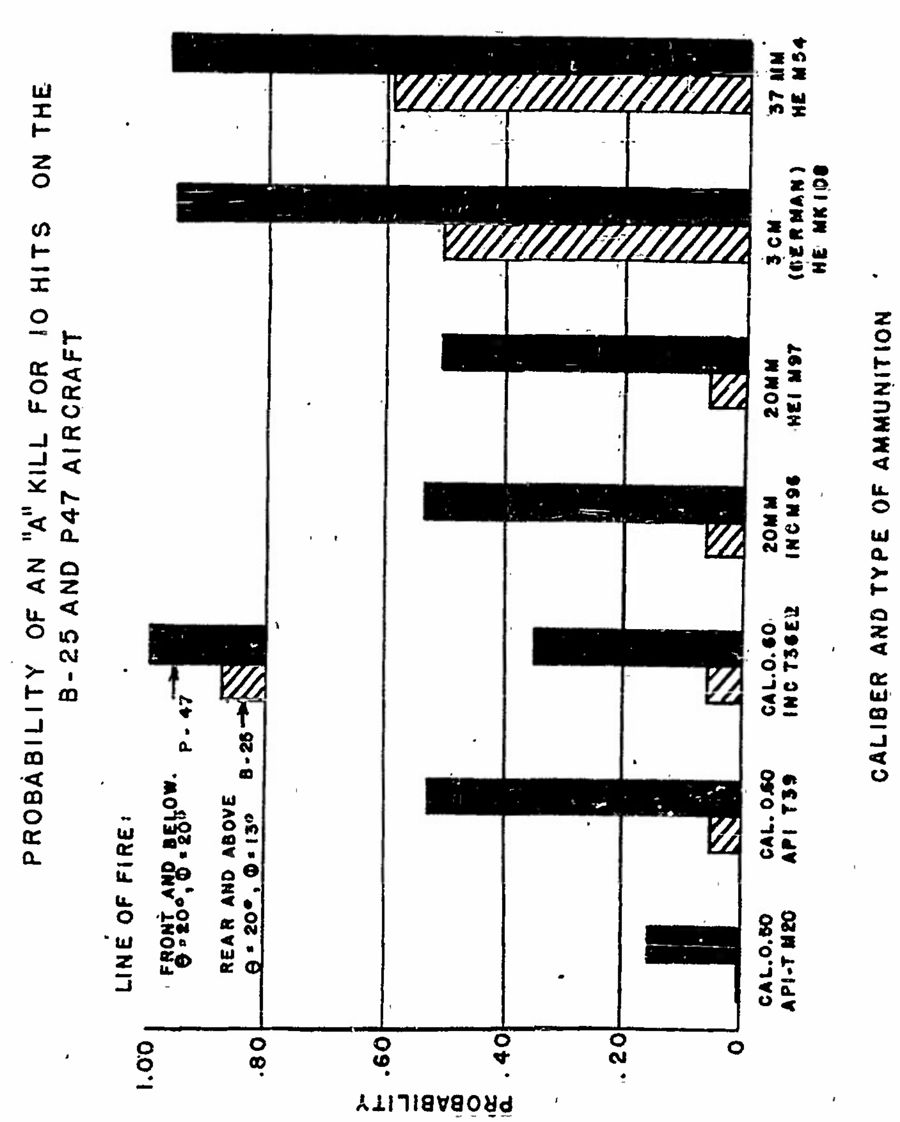


FIGURE 21

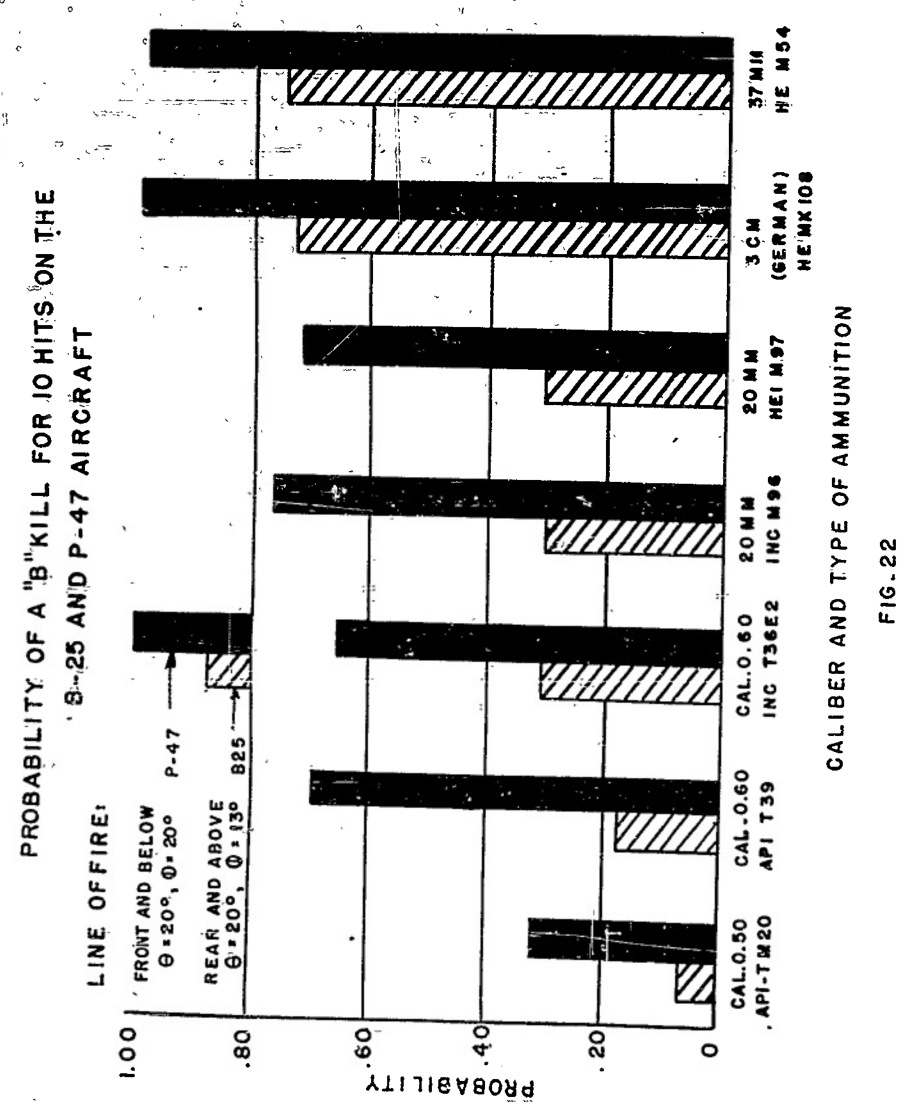
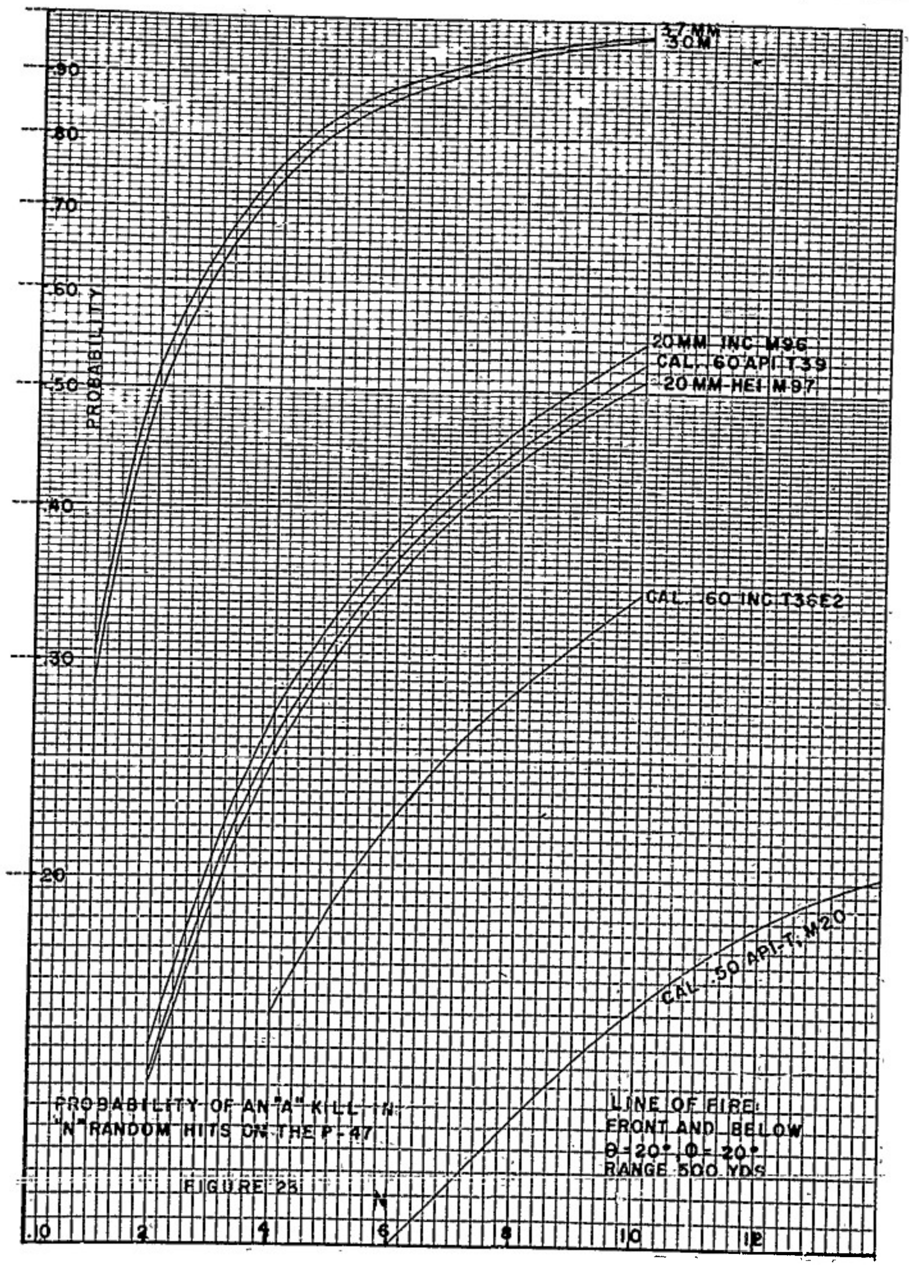
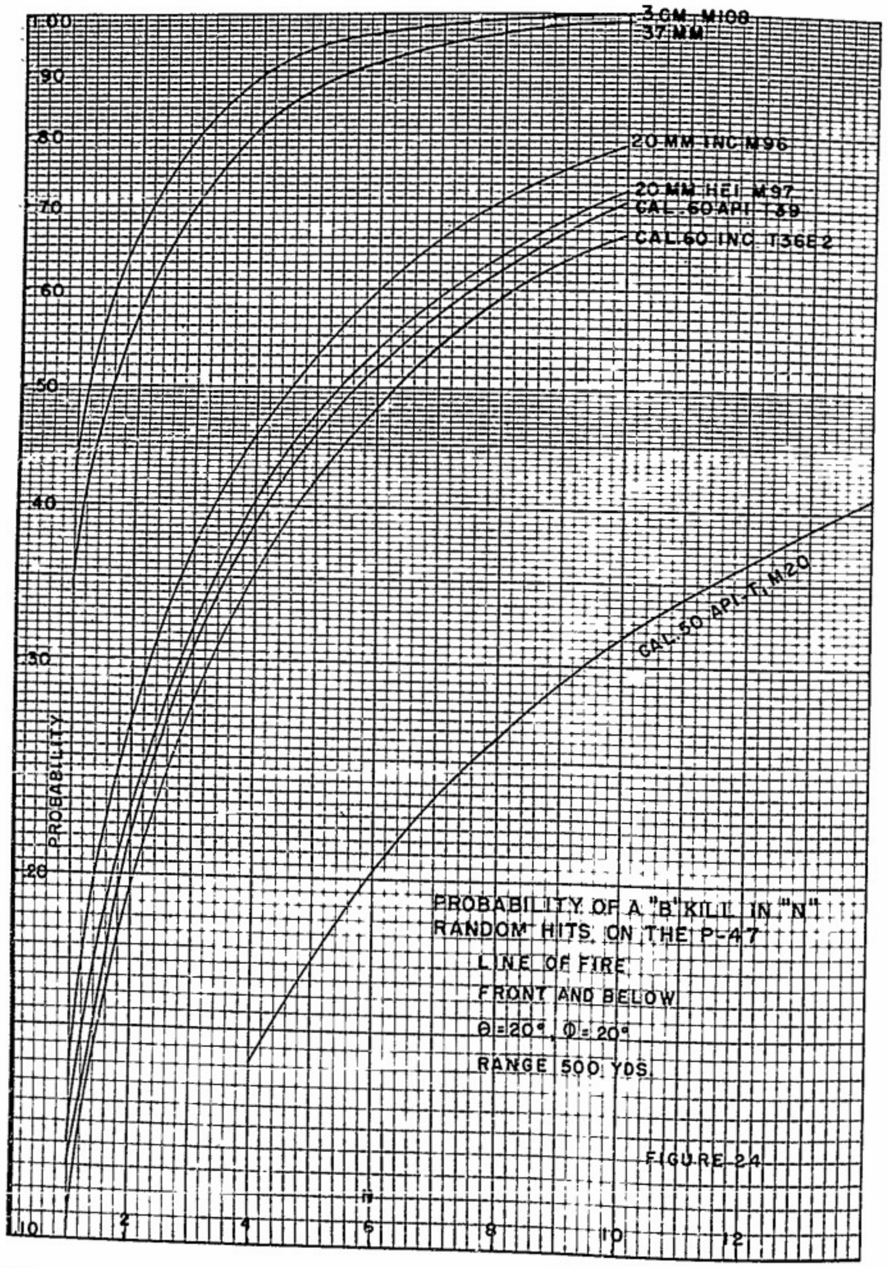
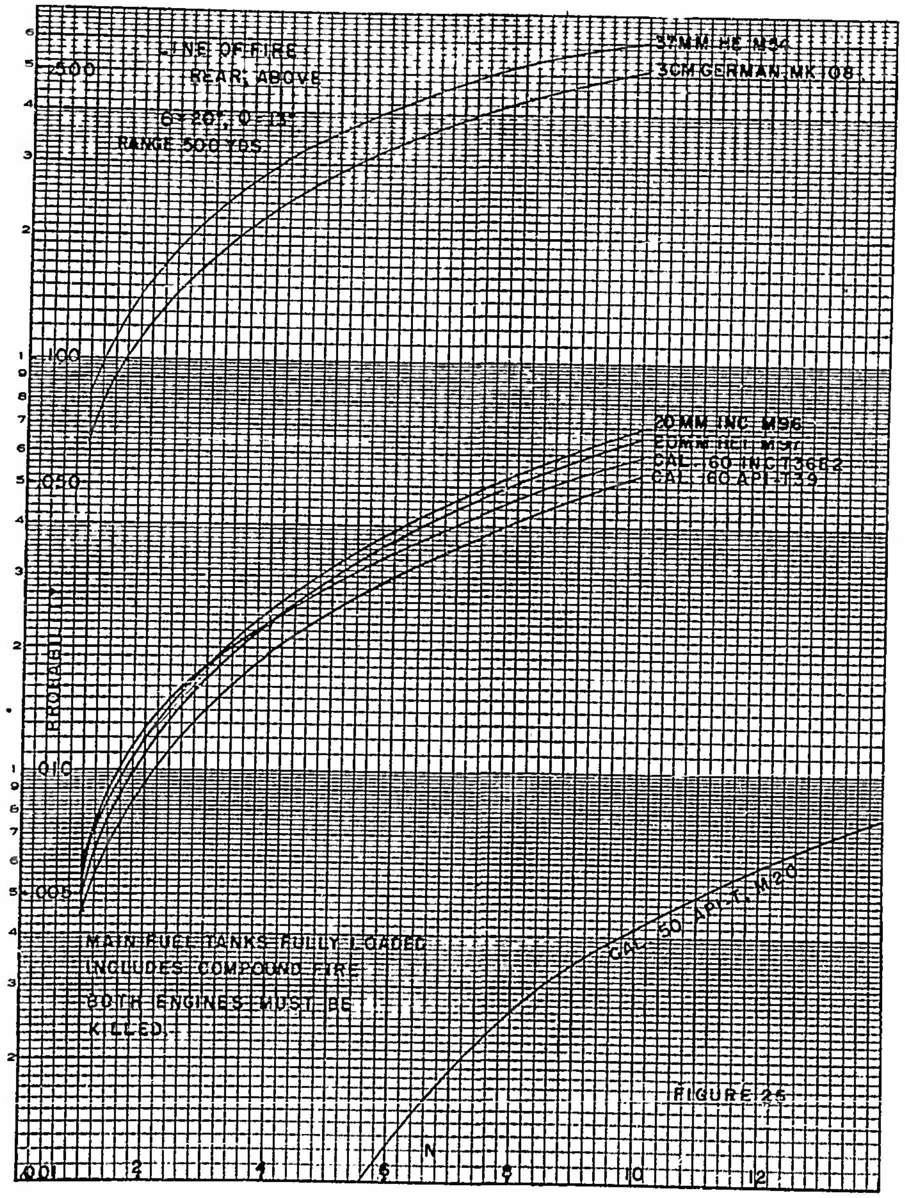

PROBABILITY OF A "B" KILL FOR 10 HITS ON THE B-25 AND P-47 AIRCRAFT
LINE OF FIRE:
FRONT AND BELOW θ=20°, Φ=20° P-47
REAR AND ABOVE θ=20°, Φ=13° B25
PROBABILITY
1.00
.80
.60
.40
.20
0
CAL.0.50 API-T M20
CAL.0.60 API T39
CAL.0.60 INC T36E2
20 MM INC M96
20 MM HEI M97
3 CM (GERMAN) HE MK 108
37 M18 HE M54
CALIBER AND TYPE OF AMMUNITION

FIG. 22


PROBABILITY
.90
.80
.70
.60
.50
.40
.30
.20
37MM
3 CM
20 MM INC M96
CAL. .60 API T39
20 MM HEI M97
CAL. .60 INC T36E2
CAL. .50 API-T M20
PROBABILITY OF AN "A" KILL - N "N" RANDOM HITS ON THE P-47
LINE OF FIRE: FRONT AND BELOW θ=20° Φ=20° RANGE 500 YDS
FIGURE 25
0
2
4
6
8
10
12



PROBABILILITY OF AN "A" KILL IN "N" RANDOM HITS ON THE B25 BOMBER



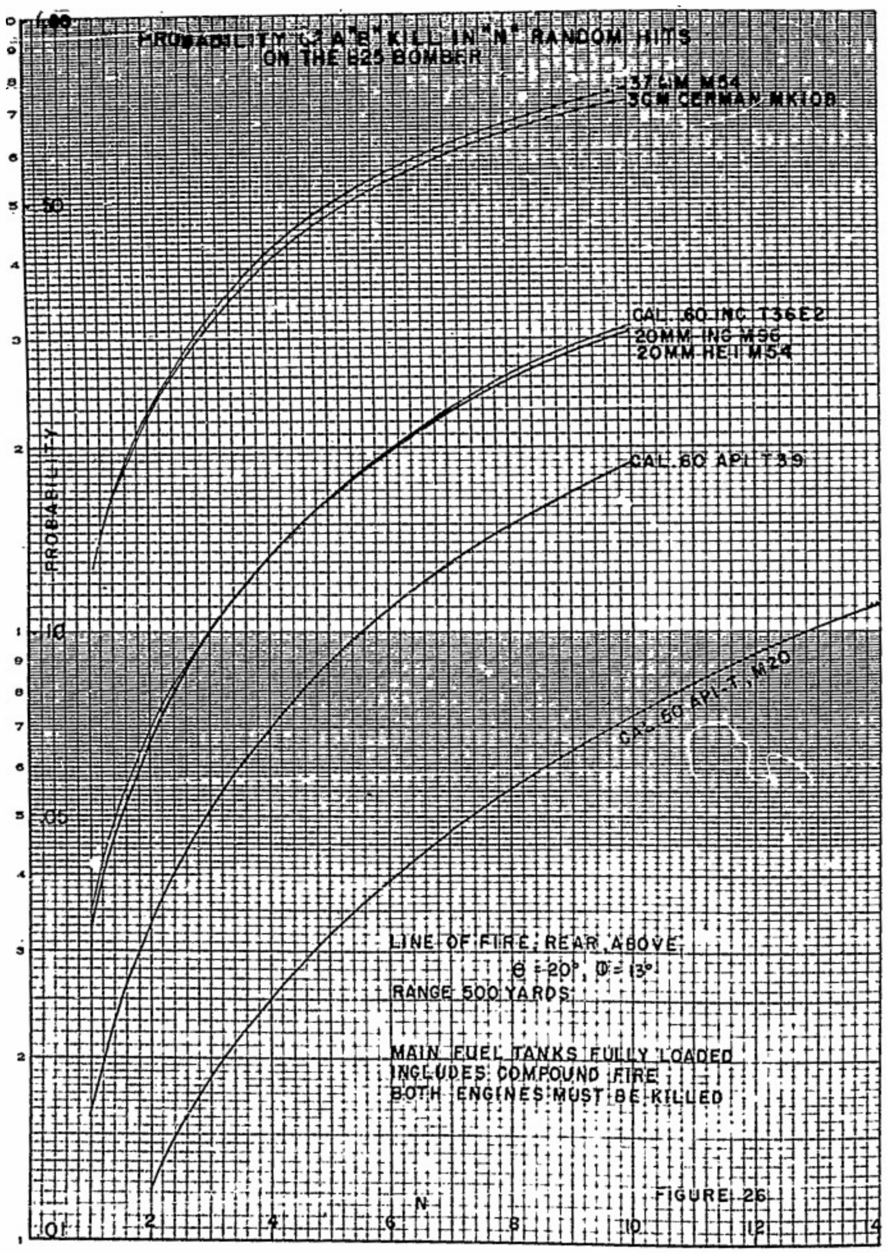


FIGURE 26

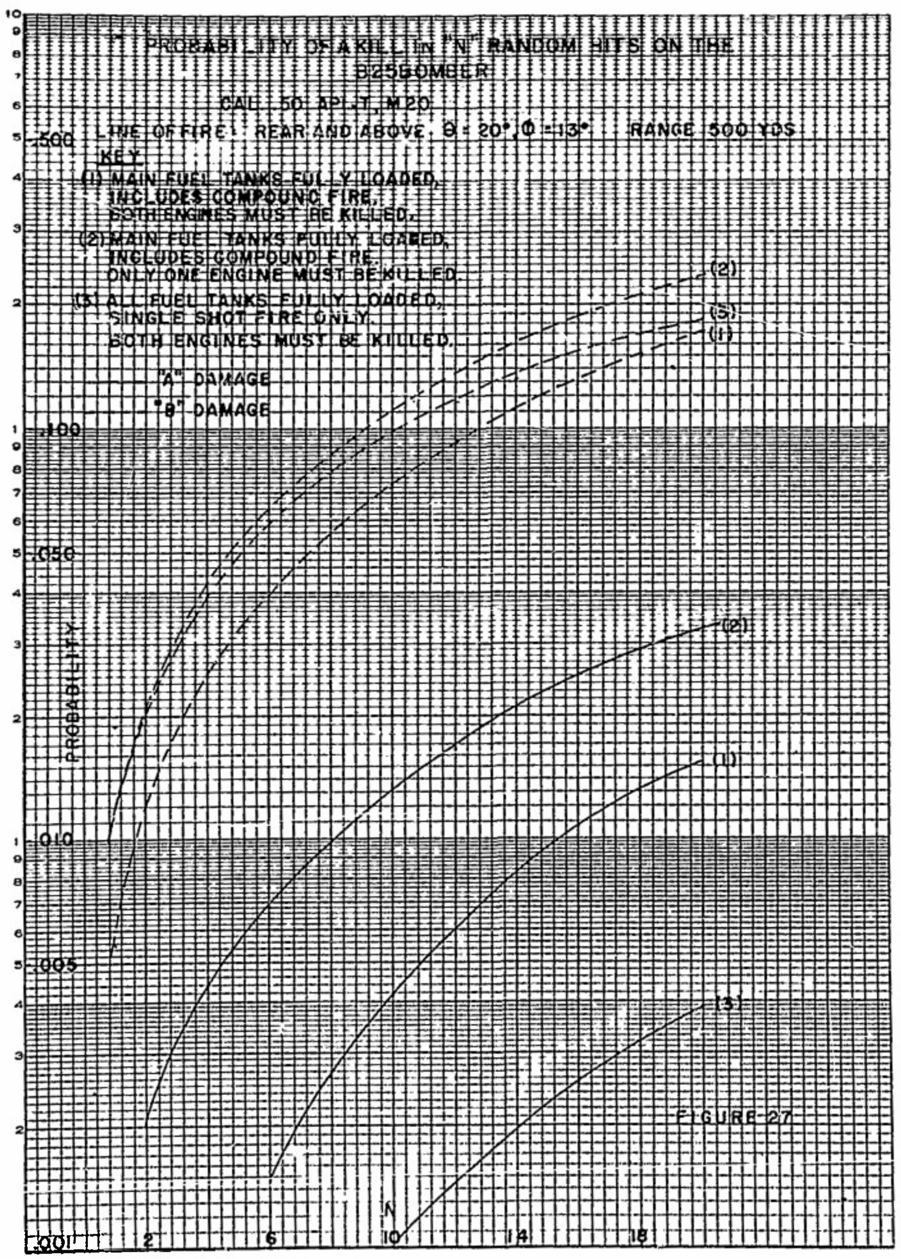


FIGURE 27

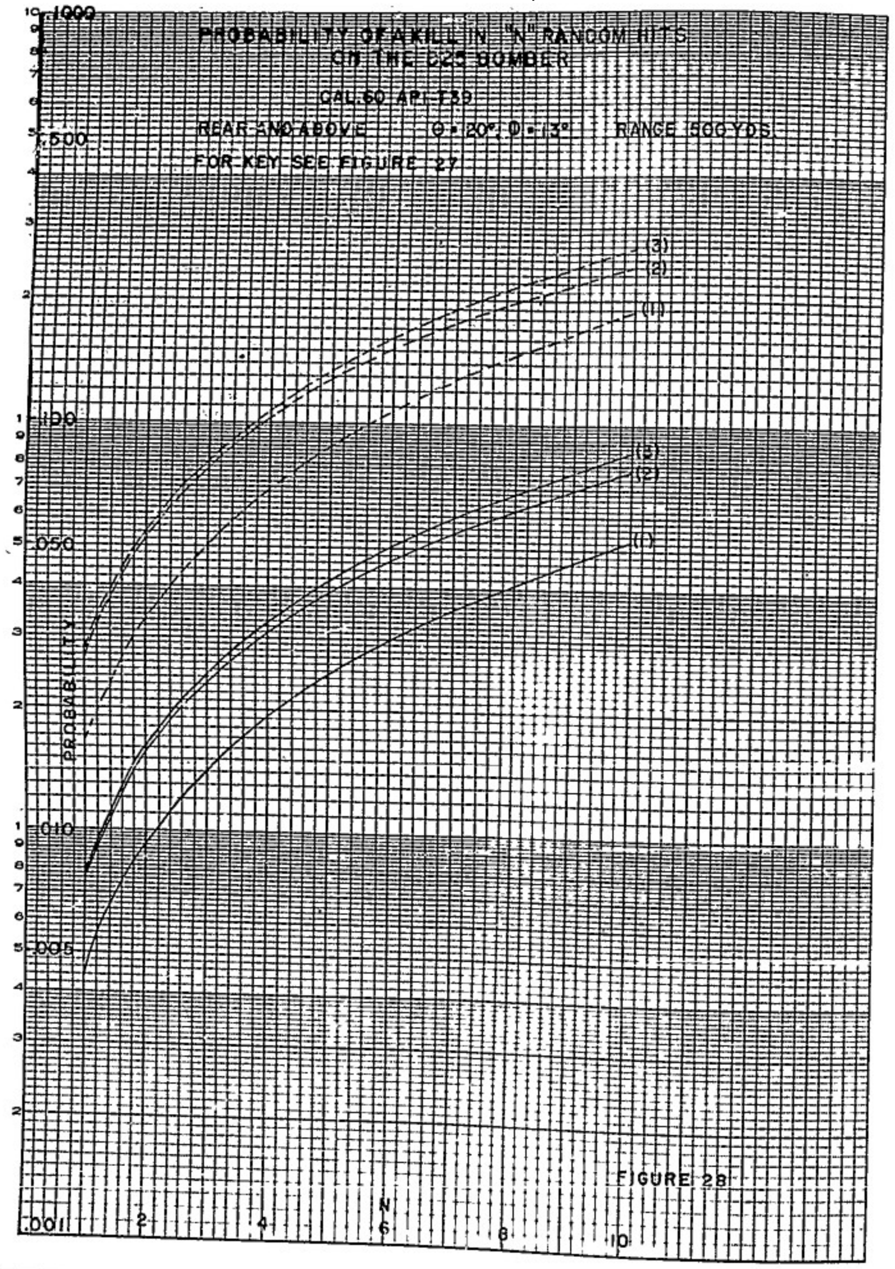


FIGURE 28

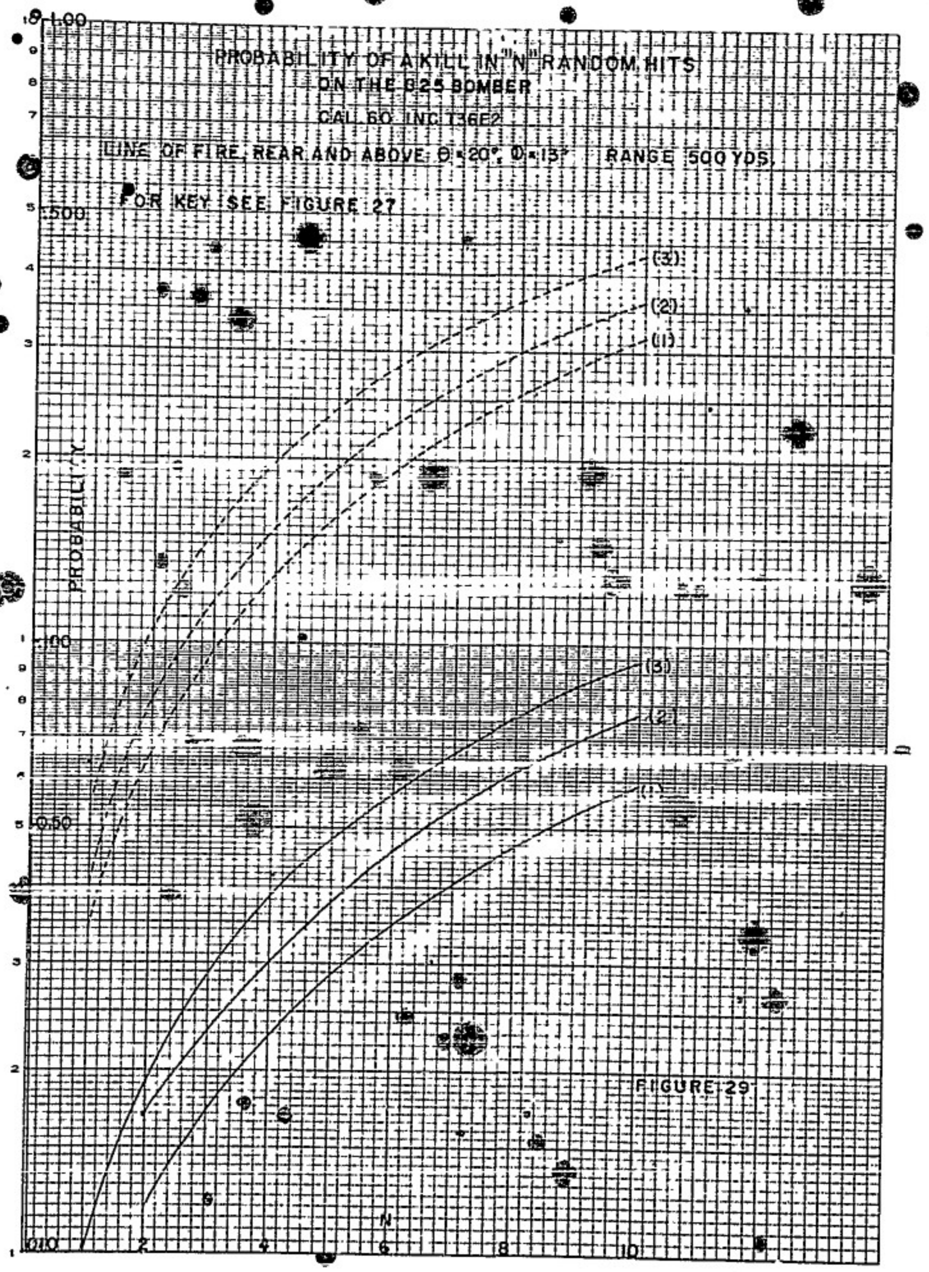


FIGURE 29

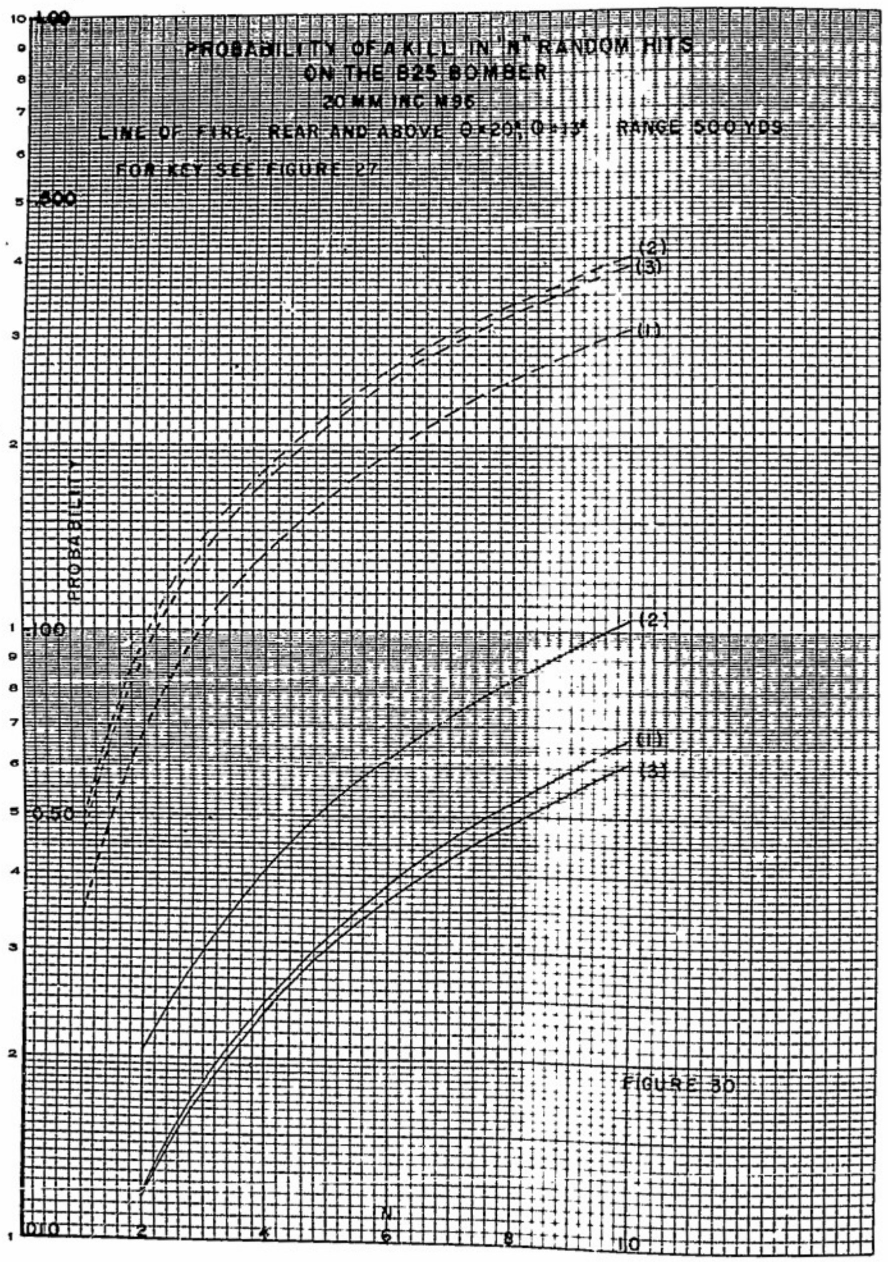


FIGURE 30

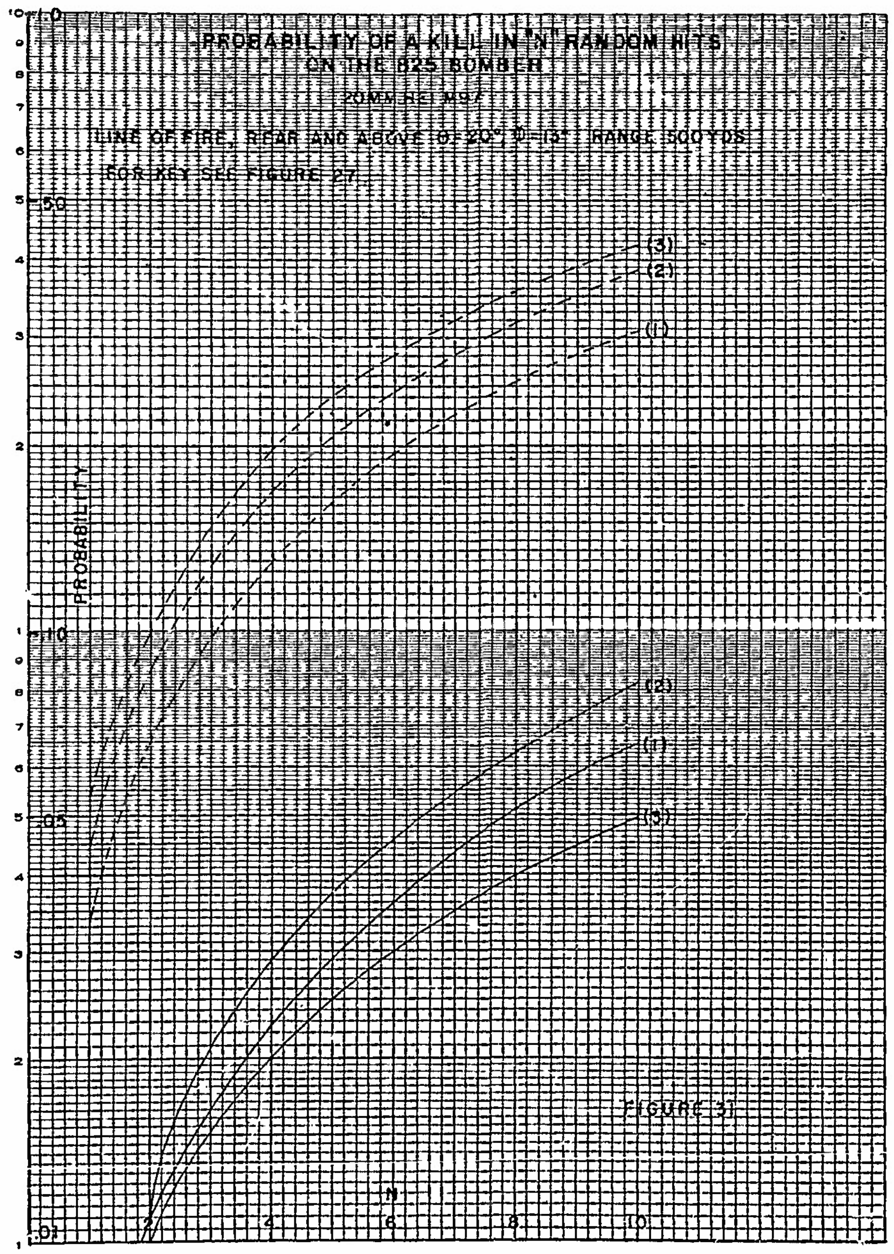


FIGURE 31

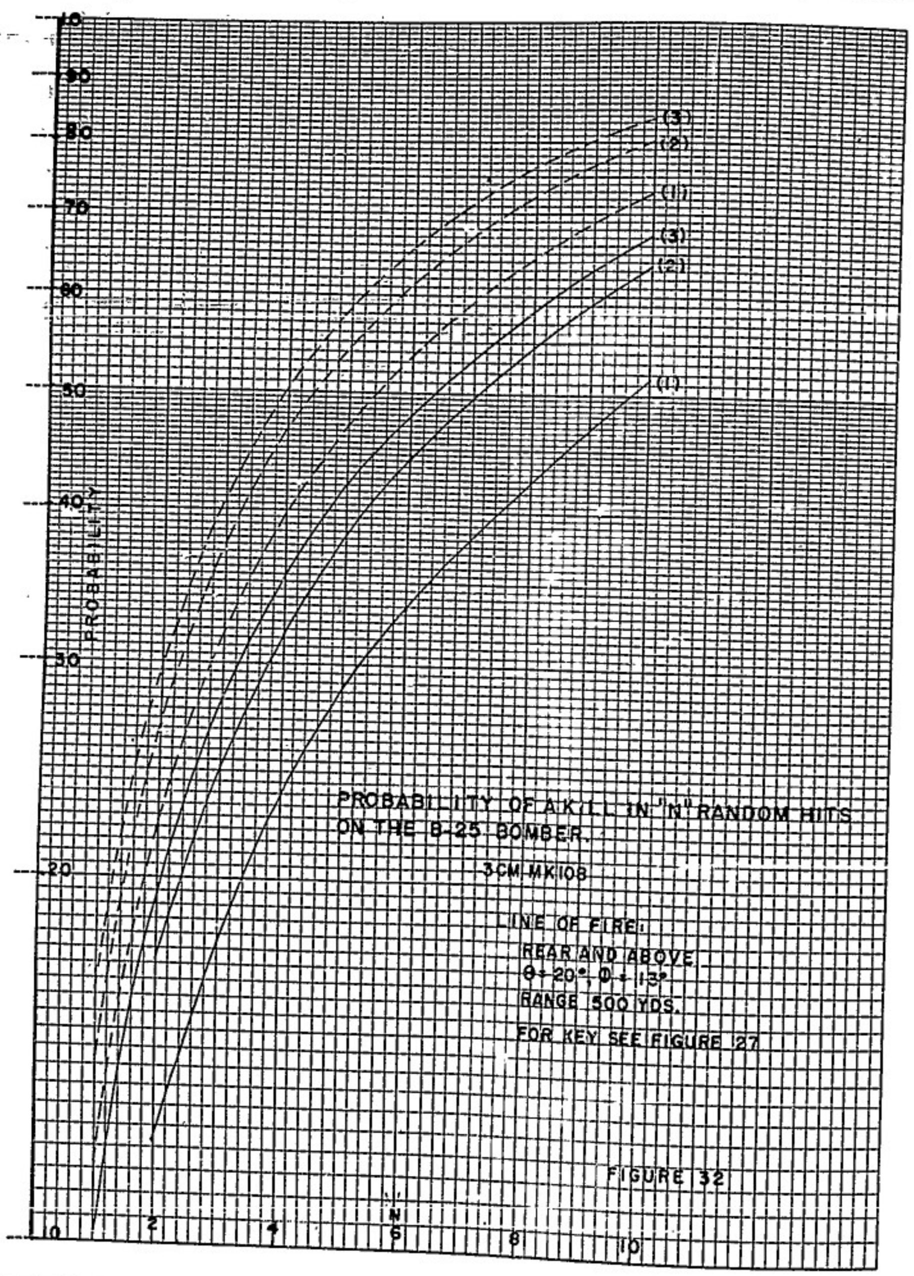


FIGURE 32

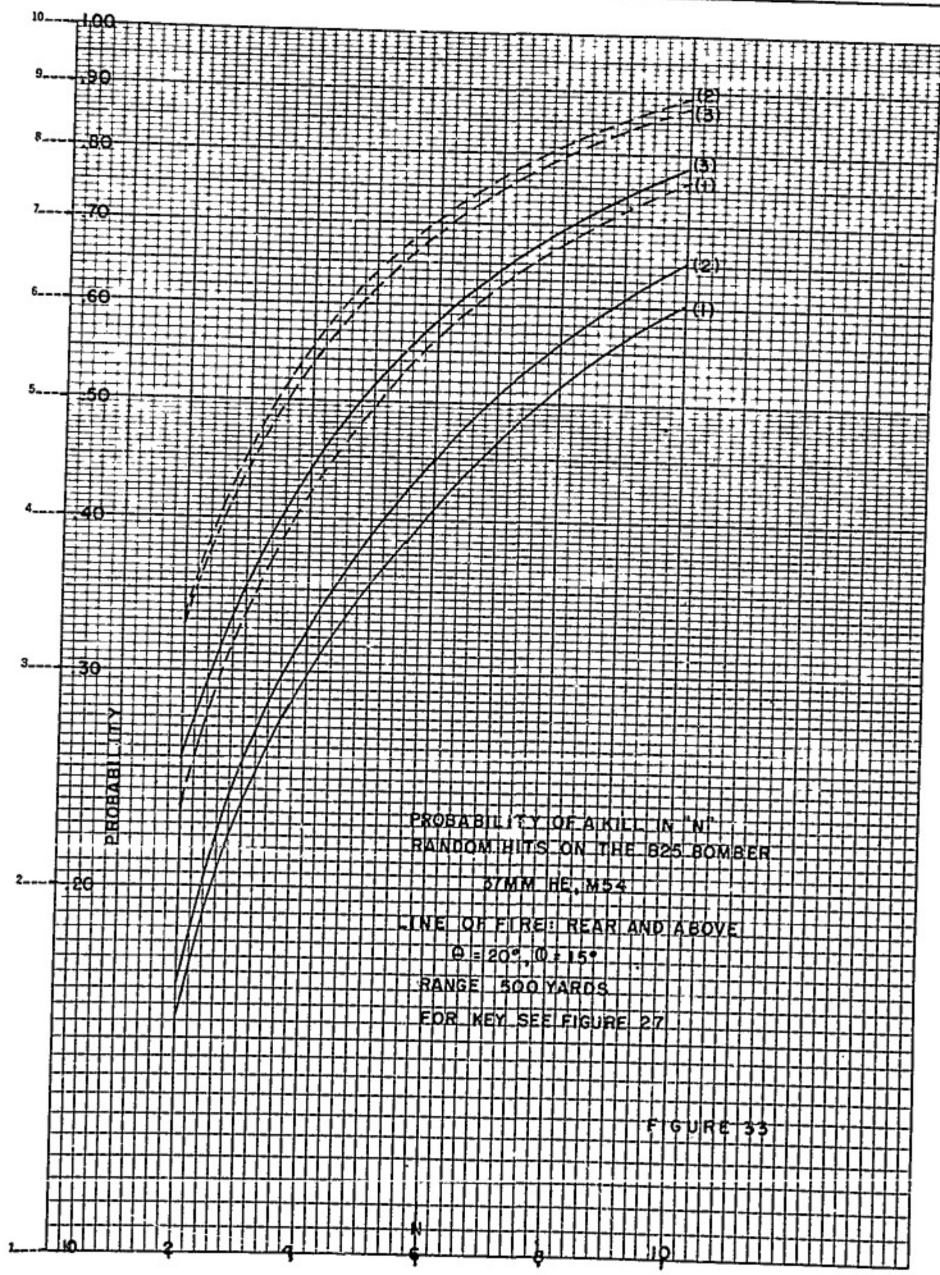


FIGURE 33

Part III

OVERALL ASSESSMENT OF WEAPON EFFECTIVENESS

INTRODUCTION

The first two parts of this memorandum report have described the experimental determination of the terminal ballistic effectiveness of the various rounds fired in the optimum caliber program and the overall computation of target vulnerability. In order to compare the overall effectiveness of the various calibers, the characteristics of the weapon and the weapon carrier must also be considered. To determine a true "optimum caliber" the possibility of varying each parameter at the control of the weapon designer must also be considered.

1. The object of the present discussion is to indicate some of the relationships existing among the many parameters affecting the overall effectiveness of an air-borne gun. The many component fields which must be investigated to contribute to the final answer will be thus made apparent. Principally, the discussion is concerned with guns as armament for bomber and fighter aircraft. The present report will be confined to an examination of the comparative characteristics of the guns of the "Optimum Caliber Program" as carried in bomber turrets and by fixed gun fighters.

2. Gun and Ammunition Characteristics: The weights, rates of fire, and dimensions of the guns and ammunition to be considered are contained in Table 7.

Of the guns described in Table 7, some characteristics such as rate of fire are known only approximately, and others, such as muzzle velocity, depend upon the number of rounds which have been fired from the gun. Table 8 lists the characteristics selected for further computations. Mean values of muzzle energy and rate of fire have been selected. Deviations of about 10% about these values probably exist. Where a number of round types of only slightly different weight are considered for a particular gun, a particular weight and muzzle energy have been chosen as representive of all of the rounds.

The weight of ammunition for 20 seconds continuous firing is tabulated, as is the time τ, for the gun to consume its own weight in ammunition. This latter figure will be shown to be of considerable importance in evaluating overall effectiveness. τ_1 and τ_2 are similar characteristic times including estimated installation weights.

With regard to ammunition weights for the small arms ammunition, the weights listed in Tables 7 and 8 may be found to differ slightly from those listed in drawings of the rounds. Comparatively large tolerances will be noted on the drawings, however, particularly with regard to the possibility of using alternative materials in the fabrication of the rounds. The manufacturing tolerances are all such as to make the average round weigh less than the weight given on the drawing. The values used in the present report are believed to represent satisfactory estimates of typical round weights.[1]

[1] Tables 7 and 8 were prepared by Mr. Norman McLeod of the Weapons Effectiveness Branch after examination of many Ordnance manuals, actual weighing of a number of rounds and clips, and consultation with members of the Proof and Development Division of Aberdeen Proving Ground.

TABLE 7

Caliber	Gun Model	Gun Ref	Gun Wt. (lb)	Comments	Length Over-all	Rate of Fire	Proj.	Muzzle Vel	Proj Wt Gr	Chg Wt Gr	Complete Round Wt Gr (lb)	Link Wt Gr	Wt of 100 Belted Rds(lb)	Muzzle Energy Ft.lb.	Tracer Inc.&HE Filler Wt. Gr.	Length Complete Round	Shell Drawing No.
0.50	M2	TM9-223	81		56-1/4"	750-850	API-T M-20	2870	608	232	1690	267 gr (M2)	27.9	11,100	21	5.42"	C7672003
	M3 (T25E3)	TM9-219	65	(Incl. 3# Access.)	58-1/4"	1200	Inc,M23	3460	495	237	1580		26.4	13,200	85	5.42	
							API,T49	3460	504		1590		26.5	13,400	17.5	5.42	
0.60	T17E3	TM9-231	126-3/4		91-1/2"	750	API,T39	3480	1140	610	3584	658	60.6	30.600	40	6.82	C7675764
							Inc, T36E2	3480	1149	610	3593	(T38E1) 658	60.7	30,900	97	6.82	C7676763
20mm	AN-M2	TM9-227	137	with M1 feed	100.8"	500-750	HEI,M97	2750	2044	490	3990	441(M3)	83.3	34.300	120*	7.23"	75-2-336
	M1	TM9-227	131	with M1 feed	100.6"	500-750	Inc, M96	2750	1933		3850	441	81.3	32,400	166.5	7.23	75-2-334
	M3 (T31)	TM9-229	111-1/2	with M2	77-3/4"	750-850											
30mm	Mk 108		154		72"	600	HE,Mk108	1650	.72#	458	1.06#		133	30.500	0.19 lb RDX/AL/wax	8.05"	
	Mk 103		298			400	HE,Mk108	2550		1750	1.91		221	73.000		10.97"	
37mm	AN-M4	TM9-240	248	with M6 Mag(30 rounds)	89.5"	150	HE.M54	2000	1.34#	.15#	1.98#	4.28 oz (T35)		83.250	0.10# Tet	9.75"	
	M10	TM9-240	231		89.6	165	HE,M54	2000	1.34	.15	1.98	4.28 oz	225w. Dis.Belt	83.250	0.10# Tet	9.75"	
	M9	TM9-241	405		104"	140	HE.M54	2600	1.34	.38	2.67	4.28 oz (T35)	294w. Dis.Belt	141.000	0.10# Tet	12.81"	75-2-279
75mm	M10 with Mount M10 AN-M5 with Mount AN-M9	TM9-312	1143 763	20 rnd. cap.	147" 116-3/8"	30 with feed M4 Hand Load	HE,M48	1970	14.70#	1.93#	19.56#		2000	886.000	1.47# TNT	26.60"	75-2-269
105mm			2100		179"	25 feed T-20	HE,M1	1900	33.00#	4.2#	42.07#		4200	1.850.000	4.84# TNT		75-4-75

*37 gr Inc

83 gr HE (Tet)

TABLE 8

Caliber	Gun	Gun wt. (lb)	Rate of fire (rpm)	Wt. 100 rounds w/links	Wt. 20s ammo (lb)	Wt. Gun /20s ammo (lb)	E_o Muzzle Energy in 10,000 ft. lb. Units	τ	Bomber Turret τ_1	Fighter Armament τ_2
0.50	M2	61	800	27	72	133	1.30	16.9	49.5	19.9
	M3	65	1200	27	108	173	1.30	12.0	33.7	14.0
0.60	T17E3	127	750	61	152	279	3.08	16.6	53.0	19.9
20mm	M2	137	750	62	155	292	3.30	17.7	56.0	21.1
	M3	112	800	62	164	279	3.30	13.6	49.6	16.8
30mm	Mk108	154	600	133	267	421	3.05	11.6	32.2	13.4
	Mk103	298	400	221	294	542	7.30	20.4	65.5	24.4
37mm	M10	231	165	225	124	355	8.33	37.3	158.5	48.1
	M9	405	140	294	137	542	14.10	59.1	244.4	75.0
75mm	M10	1148	30	2000	200	1348	88.60	114.0	912.2	121.9
105mm		2100	25	4200	350	2450	185.00	120.0	1071.4	204.6

3. Installation Weights

a. **Turret Weights:** Flexible gun mounts for bomber defense have weights which, in general, increase with the weight of the guns which they carry. Information received from Wright Field states[2] "The weight of flexible 2-gun turrets, including the complete armament installation exclusive of the gunner, is proportional to the caliber and is equal to 3200 pounds for the 37mm." Additional informal information from Wright Field indicates that the particular 37mm turret mentioned was excessively heavy, and might be lightened in a refined design.

It is necessary to estimate the separate effects of number of guns, weight of ammunition, and caliber, on turret weight, since the generalization quoted above does not permit estimation of weights of turrets with other than two guns. Table 9 lists weights[1] of standard turrets, both local and remote control, mounting two Cal. 0.50 guns; four Cal. 0.50 guns, and two Cal. 0.50 plus on 20mm gun.

It is now postulated that the weight of turrets of similar purpose and construction depends primarily upon the total muzzle energy of the guns carried by the turret. The GE and Boeing remote control turrets in Table 9, form a reasonably homogenous group for consideration, and it is seen that when turret weight

[1] Handbook of Instruction for Aircraft Designers, ATSC Manual No. 57-0-1 January 1946, Vol I (R) P 21-12, 21-40.

[2] Letter, Chief, Armament Laboratory, Engineering Division, Wright Field, to AMC Liaison Officer, Aberdeen Proving Ground, Md., 30 January 1947, subject "Information for Use in Connection with Optimum Caliber Gun Program."

less gun weight is plotted against total muzzle energy in Fig. 34, the turret weight is fairly well given in the region of the Cal. 0.50 turrets by the linear relationship

$$w_t = 100 + 90 \Sigma E_o \text{ lbs.} \qquad (1)$$

where ΣE_o is the sum of the muzzle energies of all the guns, in units of 10,000 ft. lbs. Also shown in Fig. 34 is a plot of muzzle energy against gun weight.

If now, a turret with n guns is considered, from (1), 100 lbs of weight are involved regardless of the gun characteristics. Each gun then contributes $90E_o$ to the total turret weight, in addition to its own weight and the weight of its ammunition. A time τ_1 is defined as the time required for a gun to shoot its own weight plus $90E_o$ in ammunition.

τ_1 is essentially the time required for the gun to shoot a weight of ammunition equal to its weight plus the component of turret weight associated with it. τ_1 is tabulated in Table 8.

b. **Weight of Fixed Gun Installations:** The following data on installation weights has been obtained from Wright Field[1] "The weights of fixed gun installations have been as follows:"

Caliber	Weight
0.30	50 lbs
0.50	150
0.60	280
20mm	300
37mm	390, 560
75mm	1360
105mm	2200

The agreement between the above table (which however, does not specify gun type) and the tabulated "Weight of Gun plus 20 seconds Ammunition" of Table 8 is noteworthy. Assuming that the Wright Field table refers to the M2 Cal. 0.50 and 20mm guns the agreement is to within 10%.

TABLE 9

Remote Control Turret Assemblies		Wt. w/o ammo.	Rnds./turret
GE Upper Twin Cal. 0.50 Turret	2CGD50URC	435 lb.	2000
GE Lower Twin Cal. 0.50 Turret	2CGD50LRC	440	2000
GE Upper Quad. Cal. 0.50 Turret	2CGQ50URA	812	4000
GE Upper Quad. Cal. 0.50 Turret	2CGD50URE	812	4000
GE Twin Cal. 0.50 Tail Mount (can be nose mounted)	2CGD50TRBI	486	2000
Boeing Twin Cal. 0.50 and one 20mm Tail Mount		870	2000 Cal. 0.50 120 20mm
USMC Quad. Cal. 0.50 Tail Mount		849	4000
Local Control Turret Assemblies			
A-3F Martin 2-gun Upper Turre. A-3F		630	800
Sperry 2-gun Nose and Tail Turret A-17A		680	1200
Emerson 2-gun Nose and Tail Turret A-31		556	1000

[1] Letter, Chief, Armament Laboratory, Wright Field to AMC Liaison Officer, loc. cit. sup.

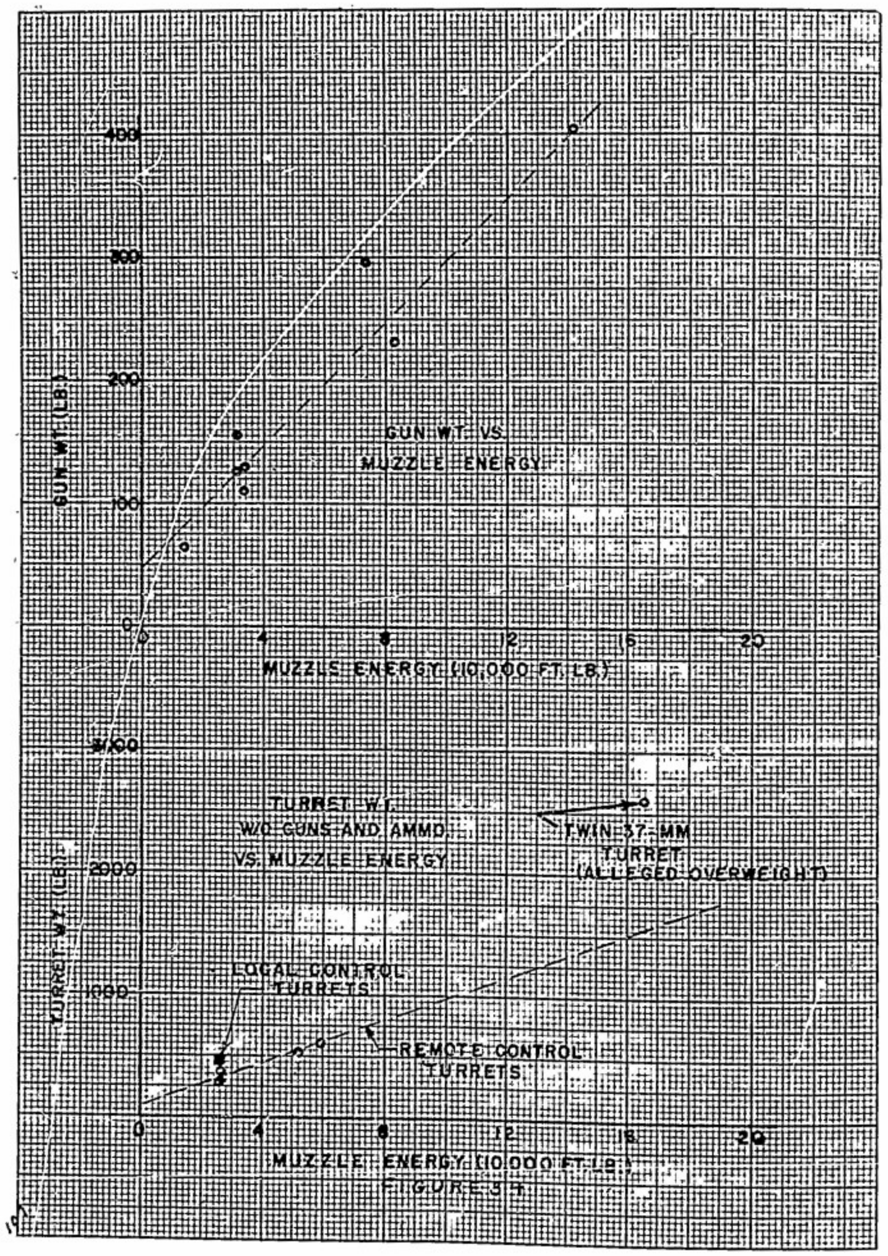


FIGURE 34

Since the above weights apparently contain ammunition weight as well as gun and mounting, the added structural weight associated with installation of a fixed gun will be arbitrarily chosen as $8E_o$, where E_o is muzzle energy in units of 10,000 ft lbs.

4. Distribution of Weight Between Guns and Ammunition: Suppose that a total weight W_t is allotted to an armament installation, consisting of guns, associated structure (mounting, turret, etc.) and ammunition. Let

w_g = weight of one gun

E_o = muzzle energy of the gun

w_a = weight of one round of ammunition with belt or clip

T = time required for the gun to fire all of the ammunition allotted to it, if it fired continuously at its specified rate of fire (although it is not necessary for the gun ever to actually do this, T being simply a convenient index)

γ = rate of fire of the gun

n_g = number of guns in the installation

Then for a turret complete with guns and ammunition, using Eq. (1)

$$W_t = 100 + n_g (90E_o + w_g + \gamma w_a T) \tag{2}$$

and for a fixed gun installation

$$W_t = n_g (8E_o + w_g + \gamma w_a T) \tag{3}$$

The maximum rate of fire is obtained from an installation of given weight by having all guns, with one round in each gun, (assuming the "given weight" is a multiple of gun weight). Then the duration of fire is zero. The maximum rate of fire γ_{fo} is

$$\gamma_{fo} = \gamma(W_t - a)/(kE_o + w_g) \tag{4}$$

where a is 100 for the turret and 0 for the fixed gun installation, and k is 90 for the turret and 8 for the fixed gun installation.

The probability of success in an engagement depends upon the total number of rounds which are fired as well as upon the rate of fire. Against a passive target, the more rounds fired, the higher is the probability of destroying the target. When the target is defended, however, these rounds must be fired rapidly enough to insure that the target be destroyed before it destroys the attacker.

The maximum number of rounds which can be carried by the armament installation and fired is that value obtained by setting $n_g = 1.00$ in (2) and (3). It is more convenient to consider N_o, the number of rounds carried if only ammunition were carried. Then

$$N_o = (W_t - a)/w_a \tag{5}$$

For any particular armament installation then, which is neither all guns nor all ammunition, the average rate of fire γ_{fa} and the total number of rounds carried by the installation are simply expressed in terms of the maximum values γ_{fo} and N_o by

$$N/N_o = T/(\tau + T); \quad \gamma_{fa}/\gamma_{fo} = \tau/(\tau + T) \tag{6}$$

where τ is the "characteristic time" of the gun plus mounting, and is the time required for the gun to shoot a weight of ammunition equal to its own weight plus its contribution to mounting weight.

$$\tau = (kE_o + w_g)/(\gamma\, w_a) \tag{7}$$

τ_1 for the turreted guns and τ_2 for the fixed guns are listed in table 8.

The variation of number of rounds carried and average rate of fire of the installation as total firing time is increased is shown in Fig. 35. The curves have physical meaning only at those values which correspond to integral numbers of guns, but for comparative purposes it is convenient to use the continuous functions. Kent[1] has remarked earlier that there is no objection to comparisons which involve intermediate points between integral numbers of guns.

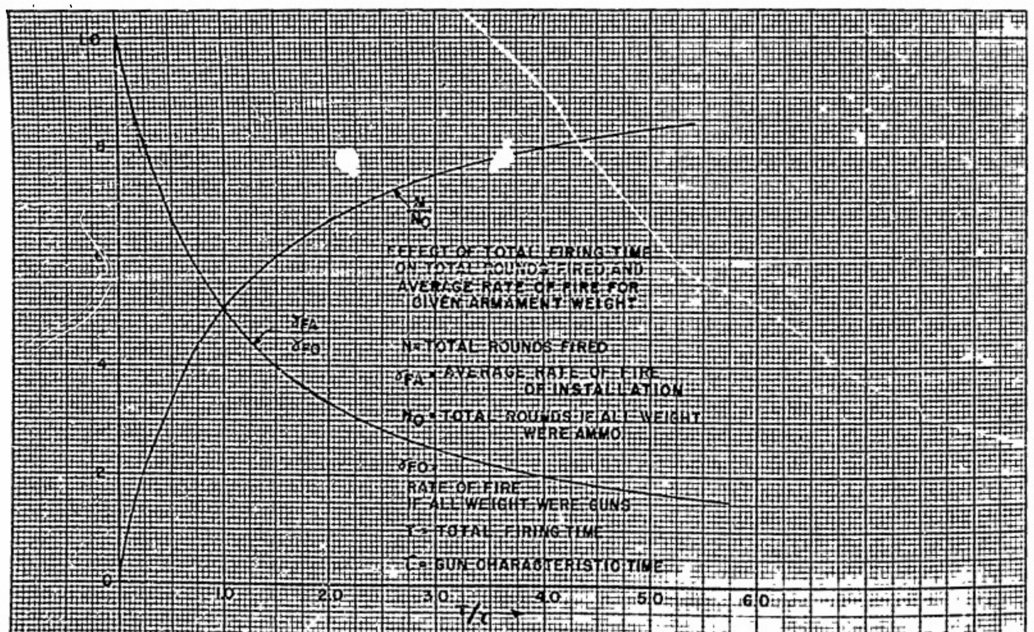


FIGURE 35

[1] "A Method of Determining the Relative Efficiencies of Two Types of Aircraft Guns," by H. H. Zornig and R. H. Kent, BRL Report 170.

Two expressions will now be recorded for later use. Suppose that a bomber turret of total weight W_t fires a short burst of length t_b at a target. The number of rounds in this burst, from prior expressions is

$$n_r = (t_b/T)\left[T/(T + \tau_1)\right]\left[(W_t - 100)/w_a\right] \tag{8}$$

or

$$n_r = (t_b/T)\left[T/(T + \tau_1)\right] N_o \tag{9}$$

Suppose that a fighter is required to fire n_f rounds at a bomber to attain an arbitrarily chosen probability of destroying the bomber. Then the time T required to fire the n_f rounds with an armament installation of weight W_t, if ammunition only for this one attack is carried, is given by

$$\tau_2/T = (W_t - a)/(w_a n_f) - 1.0 = (N_o/n_f) - 1.0 \tag{10}$$

The manner in which required weight of an overall armament installation varies with the requirement of obtaining a chosen probability of a kill in a particular firing time T is shown in Fig. 36. The dotted asymptotes of the curves are the total weights of ammunition required to achieve the desired probability.

6. Tactics and Effectiveness: It is not possible to divorce the study of effectiveness of a weapon from consideration of the tactical conditions under which it is to be employed. The effectiveness of the weapon depends upon the tactics available to the weapon bearer, and in turn, the characteristics of the weapon determine the tactics available to its carrier. In the present memorandum it will be possible to consider only very simple, and perhaps undesirably limited, tactical situations. One of the general purposes

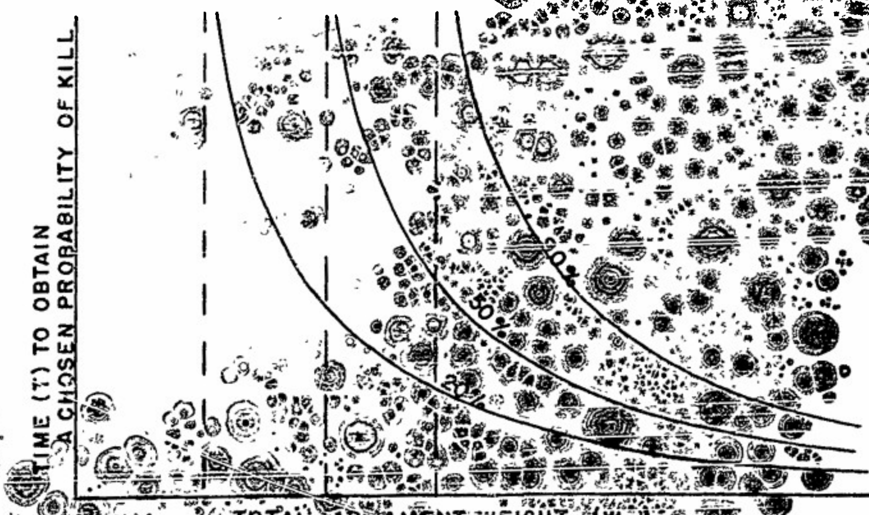


FIGURE 36

of the analytical studies in the so-called "Optimum Caliber Program", is the development of methods of analysis of the data corresponding as closely as possible to realistic combat conditions.

A simple example of the relationship between type of installation and tactics is the case of the fixed gun fighter. If the fighter is to keep the bomber continuously under fire, it is constrained to fly a pursuit type course. Such a course has the characteristic that the radius of curvature of the path which the fighter must fly becomes smaller and smaller, in general, as the fighter nears the bomber. There is a region broadside of the bomber within which the accelerations required of the fighter on a gun bearing course are so great that the bomber cannot be kept under continuous fire by a fighter in this region.

Appendix J treats the fixed gun fighter case in some detail. The "forbidden region" increases as the speeds of fighter and bomber increase. At very high speeds the fighter can close in to attack only in the nose or tail cone of the bomber. The limits for a pursuit course with lead are less severe than for a pursuit course with no lead. This is caused by the fact that the "predicted point" at which the fighter fires with correct lead moves toward the bomber as the fighter closes in, and hence has lower absolute velocity in space than does the bomber.

The size of the "forbidden region" for two of the guns of the Optimum Caliber Program is shown in Fig. 37, where it is observed that the lower velocity of the 30mm gun leads to a smaller forbidden region. This is not to be construed as an advantage for the lower velocity gun, however, since larger required lead and longer time of flight are concomitant disadvantages of low muzzle velocity.

A turreted fighter has much more freedom in choosing a course of attack. As long as only fixed gun fighters are to be encountered, increased speed is a protection for the bomber, as indicated by the figures of Appendix J. Expecting attacks only from its nose or tail, the bomber may concentrate its defense in these regions. Turreted fighters force the opening up again of the bomber's defense to include attacks from the side. The strength of the bomber's defense in any region then depends upon the number of guns which can be brought to bear in the region. In addition to selecting an angle of attack which is poorly protected by the bomber, the fighter must also seek to locate those angles from which the bomber is most vulnerable. Involved in this choice of attack angle is the area which the bomber presents to projectile impact. Fig. 38 shows qualitatively how the presented area of a typical bomber varies with angle of attack in a vertical plane, through the bombers path.

Effectiveness of combat is, moreover, largely dependent upon the "effective" ranges of the weapons involved. The fighter flying a pursuit course may present an impact area only 1/6 as great as does the bomber. For equal probability of hitting, the bomber's fire control must be correspondingly more precise. On the other hand, because of duplicated components such as engines, the bomber may be more difficult to destroy. Also, if the fighter attacks from the bomber's stern, the bomber, firing "downwind" can fire at the fighter at ranges from which the fighter's rounds cannot reach the bomber. In such a case the sequence of events in the attack may be as shown in Fig. 39.

5 "G" ACCELERATION
CONTOURS FOR 450 M.P.H.
FIXED GUN FIGHTER ATTACKING
400 M.P.H. BOMBER

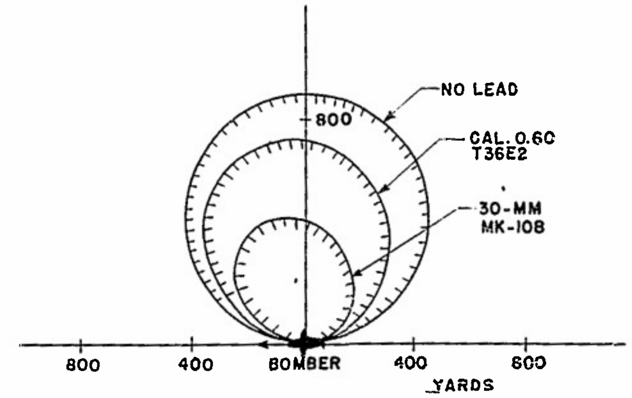
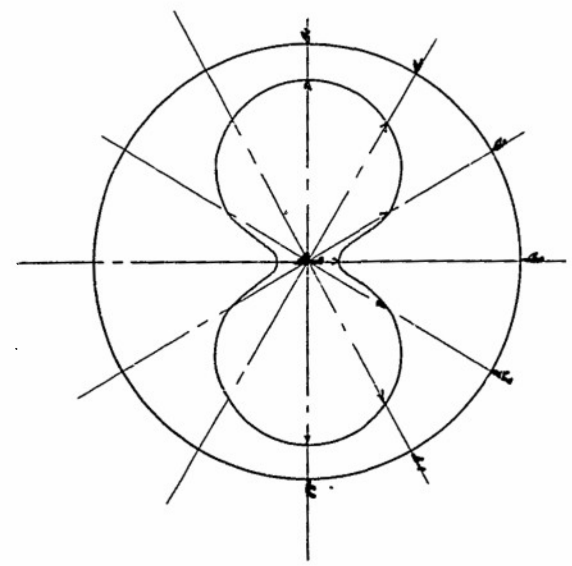


FIGURE 37



VARIATION IN PRESENTED AREA
WITH ANGLE OF ATTACK
IN VERTICAL PLANE

FIGURE 38

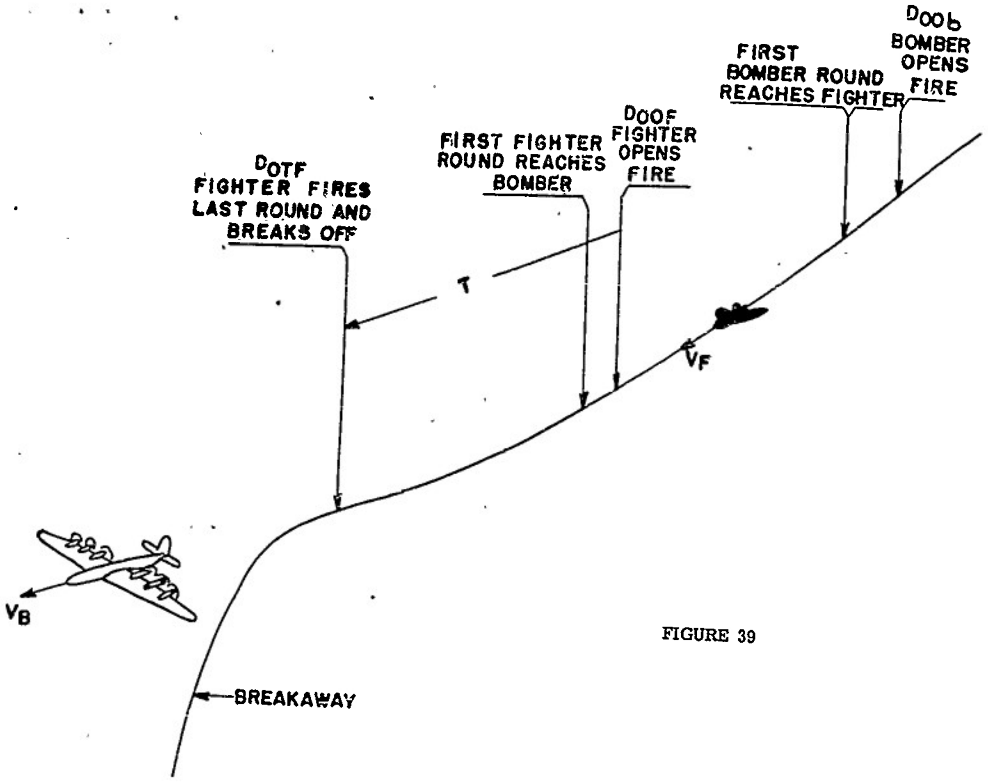


FIGURE 39

As shown in Fig. 39, the fighter must survive an initial penetration of the bomber's defense before it can, itself, open fire and attempt to win the ensuing duel.[1] In this connection, some remarks may be made concerning the qualitative effects of varying the proportions of the fighter's armament load allotted to guns and ammunition.

Consider the one-pass fighter (such as a rocket powered interceptor). Suppose that the bomber opens fire at range D_{oob} and that the fighter opens at range D_{oof}, which is less than D_{oob}. If the fighter survives to D_{oof} it opens fire and fires continuously until its ammunition is entirely consumed. For a given armament load, the relationship between total firing time and rate of fire is then as indicated by Fig. 35. The armament designer may have provided many guns with few rounds per gun, in which case rate of fire will be high and firing time short. If few guns with many rounds of ammunition have been provided the converse will be the case.

[1]The present discussion applies primarily to guns. The fighter could, of course, launch a guided missile from well outside the bomber's defense.

Now if the fighter's rate of fire is high, but the guns have only a few rounds to fire, the portion of the engagement during which the combatants fire at each other will be short, and the relative chance of the fighter winning in this portion will be high compared with the bomber's chance of destroying the fighter. But because few rounds are fired by the fighter, the absolute probability of destroying the bomber may be small, forcing the fighter to press in to a short range before opening fire, and reducing the probability that the fighter will survive the approach to firing range.

Fig. 40 shows qualitatively how the probability of destroying the bomber varies as the fighter's opening range and duration of fire are varied. The curves show variation in the probability of destroying the bomber as fighter's firing time is varied for a given opening range. It will be noted that there is both an optimum opening range for the fighter and an optimum firing time (hence an optimum distribution of armament weight between guns and ammunition).

No numerical values are attached to the curves of Fig. 40 since only approximate values of airplane vulnerability were used in their computation. They indicate one of the methods by which analysis of effectiveness of armament can be improved as information on airplane vulnerability at various ranges becomes available from the field firings.

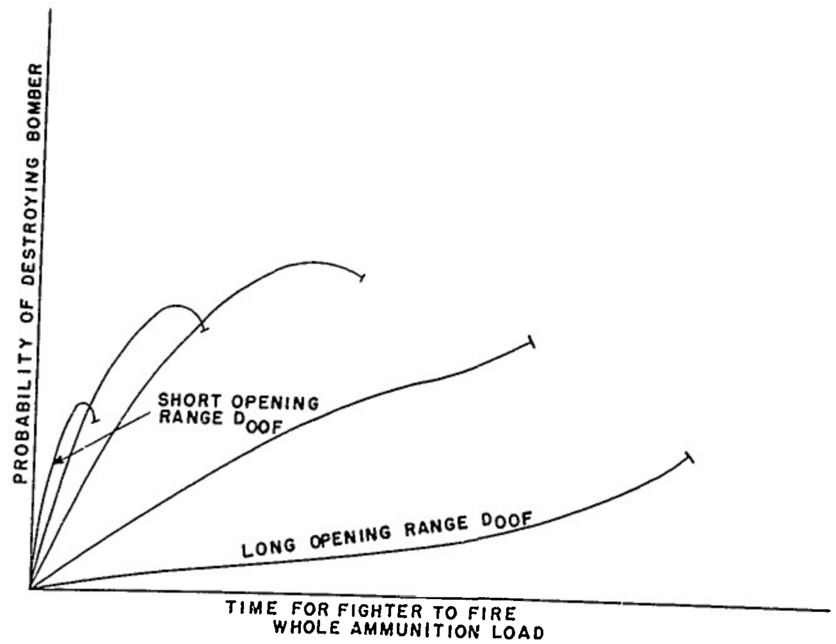


FIGURE 40

7. Probability of Hitting: The probability that a round fired from a gun strikes the target at which it is aimed depends upon the characteristics of the weapon carrier, the gun and its ammunition, the target and its flight path, the fire control system and the atmosphere. A systematic study of all of these factors and their effect on probability of hitting is being carried out, and a large amount of experimental data on the operational errors of fire control systems in dynamic ground and flight tests is available, as well as records of combat experience. It is hoped to present this analysis in future reports. For the present, more limited estimates are advanced to provide sufficient information to carry out a few computations of armament effectiveness in the present memorandum report.

a. Bomber's Errors in Aiming Guns: The following characteristics are assumed for the bomber's armament installation. Guns are assumed mounted in a remotely controlled turret. Tracking data is obtained for the computer by means of a radar which supplies both angular and range information. The computer measures rates and predicts according to the differential equation[1]

$$a u \dot{\lambda} + \lambda = u \omega. \qquad (11)$$

In this equation

- a = a smoothing parameter, chosen to be 0.20 in the present computations. Large "a" reduces the effect of input oscillations but increases the settling time of the computer.
- u = a time factor of the sight, approximately time of flight of the shell. By properly tailoring u to present slant range r, a sight obeying the simple Eq. (11) can be made to give only small systematic (instrumental) error on a selected, most probable target course.
- λ = lead computed by the sight
- ω = present angular velocity input to the sight

The computer also has associated ballistic circuits, but it is assumed that these function without error, and that the only errors in computation of predicted position of the gun result from the insertion of erroneous range and angular information to Eq. (11). This anticipates a computer considerably more satisfactory than present standard computers which may have very large instrumental errors in certain regions of operation.

(1) Effect of Range Error on Prediction Error

Examination of some test data on the AN-APG-5 airborne ranging radar at Armament Test Division, U.S. Naval Air Station, Patuxent River, indicated that errors in ranging tended to be substantially constant over a course, and for this series of tests were occasionally as large as 20 yards. Only small deviations about this bias were recorded during a course. This error should probably be treated as random across courses, for if it could be anticipated, it could be removed by calibration. Further study of radar ranging errors is required for future reports.

[1]This smoothing-plus-predication equation forms the basis for many of the lead computing sights and directors developed during World War II.

The effect of these errors on lead computed by Eq. (11) may be estimated as follows. A simple formula for λ is given by Hestenes[1] adapted from some work by Sterne[2] when the target is a fighter flying a pursuit course. It is

$$\sin \lambda \cong k r \omega / v_o; \; k = 1 - v_f/2v_o \qquad (12)$$

where r is present range, v_f is fighter speed, v_o is muzzle velocity of the bomber's guns. Then assuming that λ is sufficiently small so that $\sin \lambda \cong \lambda$, and observing that for the pursuit course

$$u \cong kr/v_o; \; \omega \cong v_b \sin \alpha / r \qquad (13)$$

where v_b is bomber speed, and α is angle of the fighter off the bomber's tail, the standard deviation of prediction error $\sigma_{\lambda r}$ resulting from an input range error of standard deviation σ_r is approximately

$$\sigma_{\lambda r} \cong (k\omega/v_o)\, \sigma_r \cong \left[k v_b \sin \alpha / (v_o r) \right] \sigma_r \qquad (14)$$

(2) Effect of Angular Tracking Error on Lead Error

The angular errors of a radar tend to be highly oscillatory. Fig. 41 is a typical record of azimuth error and Fig. 42 of elevation error.[3] A 20 mil bias was removed from the data since no attempt was made in these runs to calibrate out angular bias, although this was proven feasible in later runs. The target was a fighter 300 yards off the bomber's tail. The average amplitude of error decreased somewhat as range increased, but the frequency composition of the error did not change appreciably with range in this series of tests. Rough air and violent target maneuvers changed both amplitude and frequency composition of the errors.

The following is a brief outline of the method employed to compute the effect of recorded tracking errors such as those of Fig. 41 on the prediction error of a hypothetical computer as defined by Eq. (11). First assume that range rate is small enough so that the changes in "u" can be neglected. Then Eq. (11) is linear with constant coefficients, and the λ computed from any sum of inputs is the sum of the λ computed if each were applied separately. The lead computed for erroneous ω, is then the lead computed for perfect ω plus the lead computed if only the deviation in ω from the true value were supplied. Subsequent development therefore deals only with the error in ω as indicated by Fig. 41.

[1]"Deflection Formulas for Airborne Fire Control", by M. R. Hestenes, AMP Report 104.2, Oct. 1945, pp 14 to 16.

[2]"On Direct Firing Tables for Flexible Aircraft Gunnery, with Particular Reference to Caliber 0.50 A.P. M2 Ammunition," by T. E. Sterne, Ballistic Research Laboratory Report No. 396.

[3]"Report No. 45810", "AN/APG-3 (XA-1) Installation Approval Tests," General Electric Company, Schenectady, N. Y. It is hoped to present a complete analysis of the data in this report in a later study.

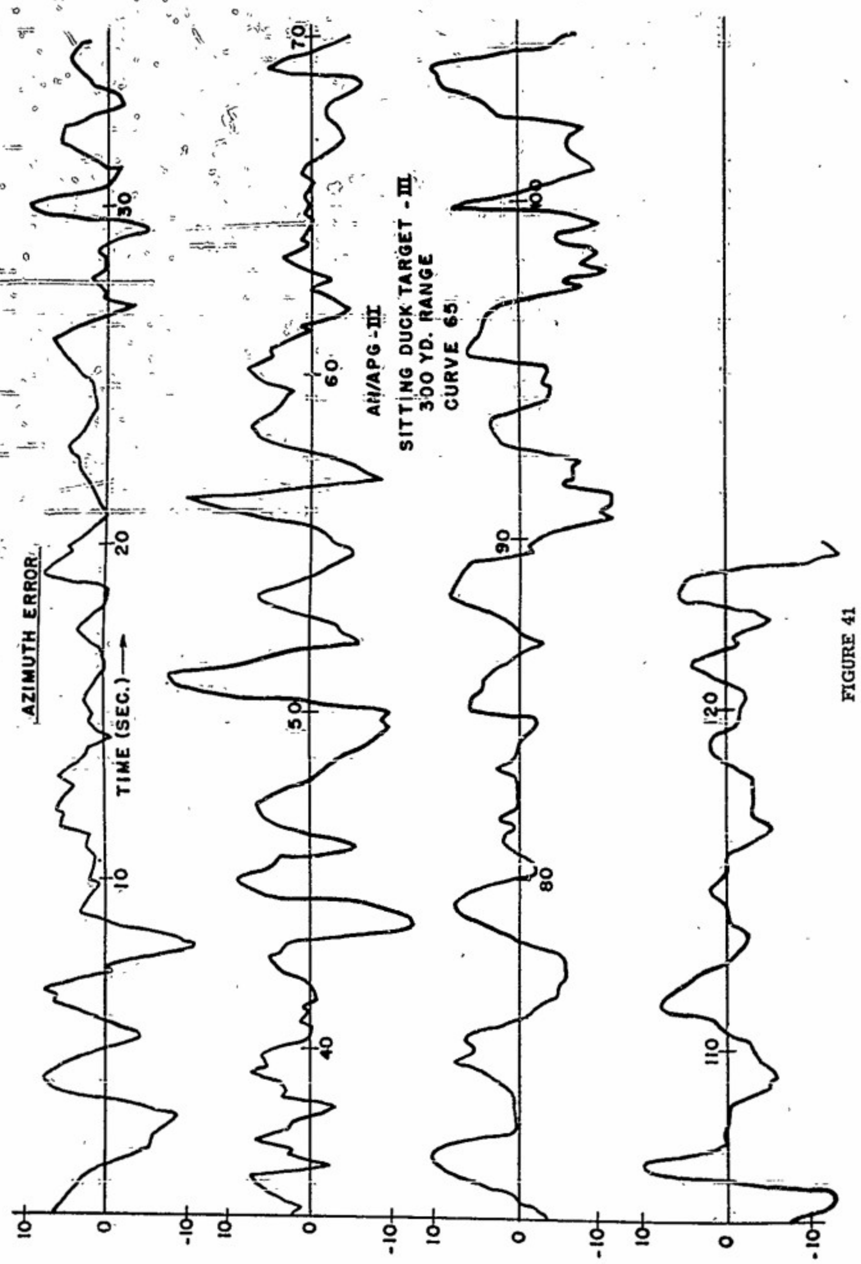


FIGURE 41

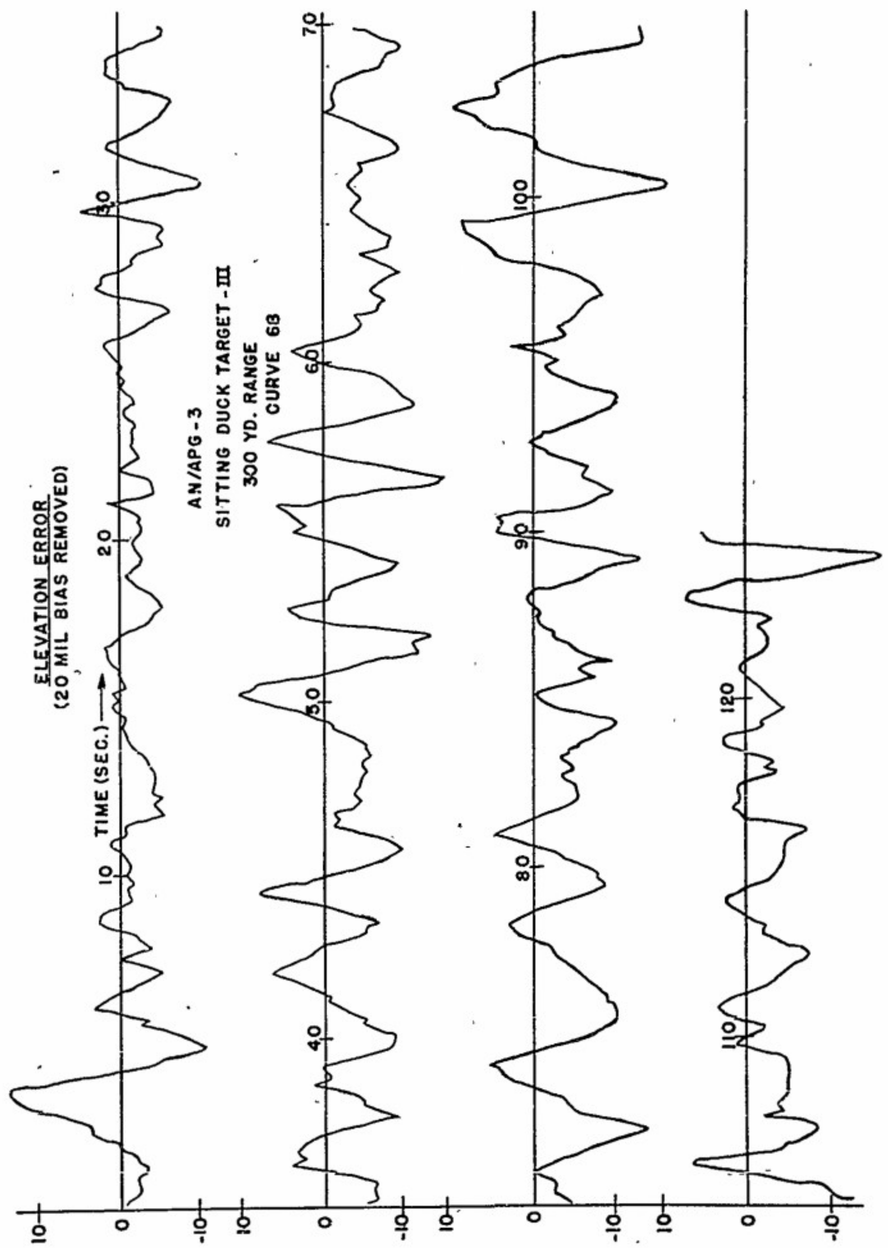


FIGURE 42

Let A(s) be the response of the computer to a unit change in input angle. From Eq. (11)

$$A(s) = 1 / (1/a)e^{-s/au} \qquad (15)$$

where s is time.

Then the output of the computer $y_p(t)$ at time t, resulting from any arbitrary input which is a function of time $y_o(t)$, such as the record of error in Fig. 41, is by the Boltzmann-Duhamel superposition theorem[1,2]

$$y_p(t) = A(0)y_o(t) / \int_0^{\infty} y_o(t-s)\, A'(s)\, ds \qquad (16)$$

This expression could be evaluated numerically. A'(s) decreases rapidly enough with s so that the integral need not be carried more than a few seconds back into the past from t.

For present purposes, only the standard deviation of y_p is required. The standard deviation of input and prediction errors are defined by

$$\sigma_p^2 = \frac{1}{2} \int_{-T}^{T} \overline{y_p(t)^2}\, dt \qquad (17)$$

$$\sigma_o^2 = 1/2T \int_{-T}^{T} \overline{y_o(t)^2}\, dt \qquad (18)$$

where 2T is the length of the course over which the error is recorded. Difficulties with the integrals at the course extremes can be avoided by assuming $y_o(t) = 0$ outside these limits. (The computer gyros might be considered caged, for example).

The ratio $\sigma p/\sigma_o$ is represented by μ, the amplification of the computer. Substituting (15), (16) and (18) into (17), and performing the integration, the result is obtained that

$$\mu^2 = (1 / \tfrac{1}{a})^2 - \left[(1 / \tfrac{1}{a})^2 - 1\right] /au \int_0^{\infty} \phi(s)e^{-s/au}\, ds \qquad (19)$$

where

$$\phi(s) = 1/(2T\ \sigma_o^2) \int_{-T}^{T} y(t)y(t/s)\, dt \qquad (20)$$

is Wiener's autocorrelation function,[3] a quantity easily computed from the tracking errors on IBM machines. Fig. 43 shows the autocorrelations computed from the data of Figs. 41 and 42. The quantity $e^{-s/au}$ in (19) determines the relative importance of ϕ at various s. For u < 2. seconds and a = 0.20 only the values for s < 1.0. second affect the result and there is no significant difference between the curves in this region.

[1] See for example, "Operational Circuit Analysis" by V. Bush, John Wiley and Sons, p. 57.

[2] A much more detailed description of this method has been presented by one of the authors in an earlier memorandum, Memo. H. K. Weiss to Director Antiaircraft Service Test Section, Army Ground Force Board #1, Ft. Bliss Texas, 19 Nov. 1945, Subject "Computation of Prediction Functions."

[3] N.D.R.C. Division 2 Report to the Services, by N. Wiener, 1 Feb. 1942 "The Extrapolation, Interpolation, and Smoothing of Stationary Time Series".

Eq. (19) was evaluated numerically for the whole-course azimuth autocorrelation shown in Fig. 43 and the corresponding values of μ are shown in Fig. 44.

Note that the autocorrelations have the general form of damped sinusoids

$$\phi(s) = e^{-s/Td} \cos \omega s \qquad (21)$$

In terms of (21), Eq. (19) becomes

$$\mu^2 = (1 / \tfrac{1}{a})^2 - \left[(1 / \tfrac{1}{a})^2 - 1\right]\left\{\frac{1 / \frac{au}{Td}}{(1 / \frac{au}{Td})^2 / (\omega au)^2}\right\} \qquad (22)$$

where ω is approximately the dominant frequency in the tracking error (about 2.3 rad/sec) and T_d is an index of distribution of the error among other frequencies (about 1.7 seconds).

(3) Combination of Errors: For the present report, standard deviation σ_o of vertical and lateral tracking errors will be assumed equal. Target in the tail cone of the bomber only will be considered. Then letting $\sigma_{\lambda t}$ be the contribution of angular tracking error to prediction error (up to this point referred to as σ_p)

$$\sigma_{\lambda t} = \mu\sigma_o \qquad (23)$$

The standard deviation of aim in the plane of action is given by

$$\sigma hx^2 = \sigma_{\lambda t}^2 / \sigma_{\lambda r}^2 \qquad (24)$$

and the standard deviation of aim perpendicular to the plane of action is given by

$$\sigma hy^2 = \sigma_{\lambda t}^2 \qquad (25)$$

Only short bursts will be considered, over which the deviations of the point of aim, h_x and h_y are substantially constant. Their values, however, are assumed to be drawn from normal distributions with standard deviations as given by (24) and (25).

A few remarks are appropriate at this point concerning the aim error. The aim error is not exactly repeatable over many courses. Hence it is not correct to assume a particular deviation of the point of aim from the airplane (such as 5 mils) to combine with the gun dispersion, any more than it is correct to assume in advance that one knows what the deviation of a particular round from the point of aim will be. Errors in point of aim, like ammunition dispersion can be properly described only by statistical parameters.

Fig. 45 shows the recorded overall error in aiming a turret with a Mk-18 type of computing sight[1], for a number of courses. The data was taken in actual flight tests. The following comments may be made

[1] Final Report on Mk.18 Sight Test in Erco TH Turrets, Project PTR 32154 4 May 1946, Armament Test, U. S. Naval Air Test Center, Patuxent River, Md.

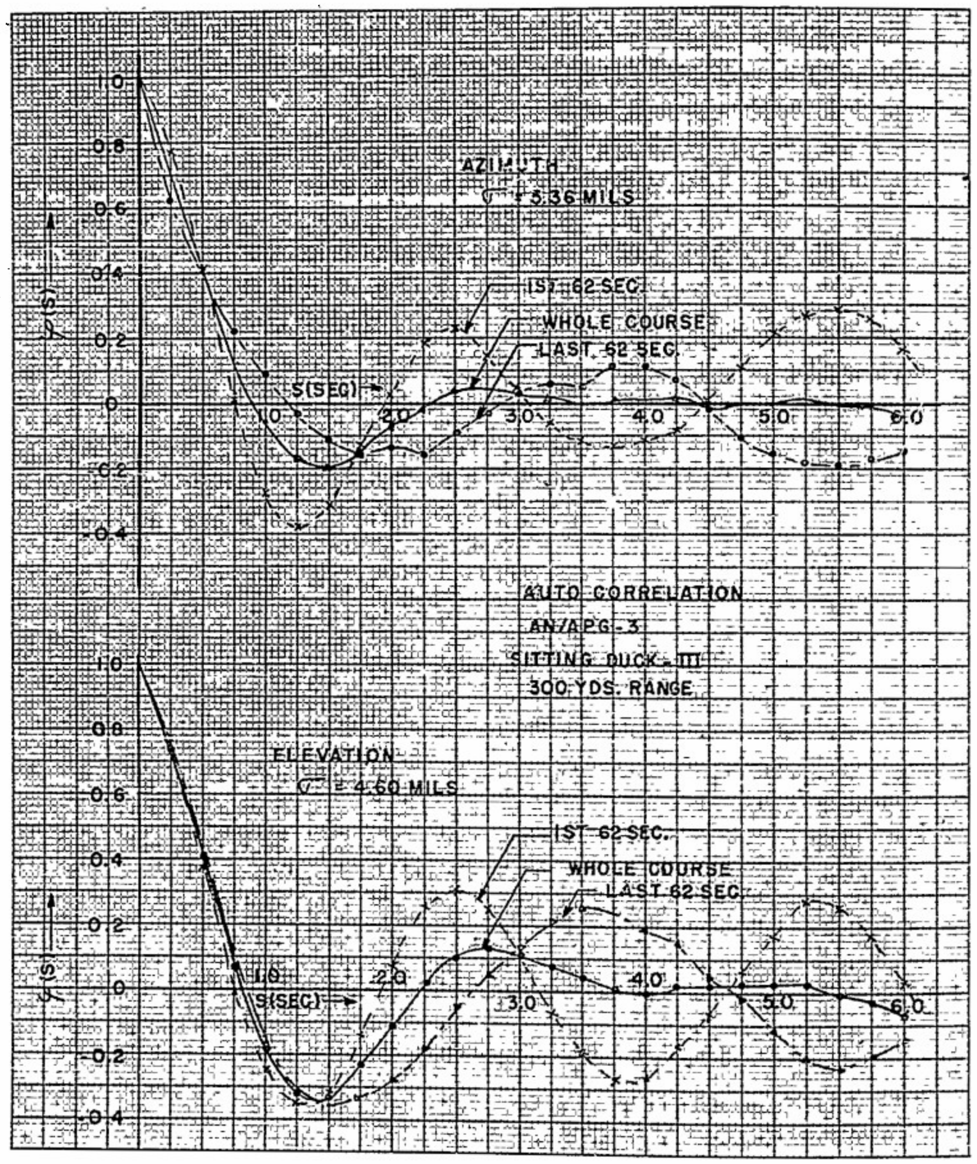


FIGURE 43

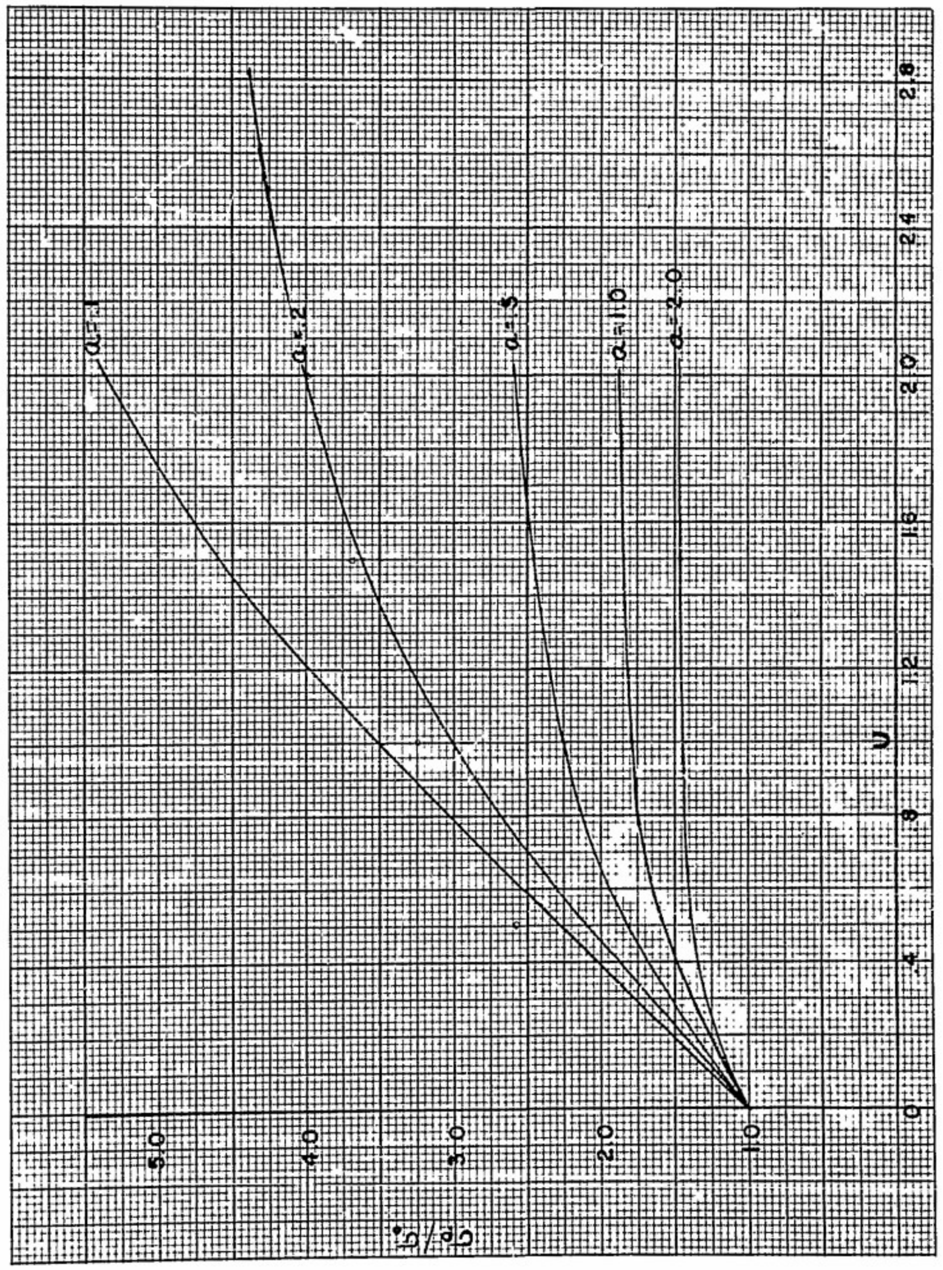


FIGURE 44

a. The error is never the same on successive courses

b. The error varies during a course

c. The error is rarely near zero or excessively large

The actual errors shown in Fig. 45 are not indicative of accuracies of fire control systems under development, since range input was by stadiametric ranging. This source of range is much less accurate than radar. The variations in error may be considered typical, however.

In the present report the aim error will be assumed constant over a short burst, but varying across courses in a manner described by a Gaussian distribution. Methods for accounting for the variation of the error with time for a long burst are also available, thanks to work by Dr. T. E. Sterne, and will be employed in succeeding reports.

(4) Dispersion of Turret plus Guns: Superimposed on the aiming errors h_x and h_y is the dispersion of turret, guns, and ammunition, which will be considered random between rounds. It is probably more diffic to keep dispersion small for a turret mounting large guns than for a turret mounting small guns. It is hoped to obtain information regarding this variation. For the present, the same value of dispersion will be assumed for all of the gun-turret combinations considered.

a. Fighter's Errors in Aiming Guns: The fighter is assumed to carry fixed guns and a lead computing sight. Eq. (11) still defines the method of lead computation, although the computing circuit now constitutes a "disturbed reticle sight" instead of a computer. A value of "a" of 0.42 is typical of fighter sights.[1]

Unfortunately for analytical purposes, in the case of the lead computing sight, the dynamics of the tracking system (sight plus plane plus pilot) are affected by parameter "a", hence the method of analysis employed for the bomber's fire control cannot be employed.

The following information regarding tracking errors of a fighter aircraft has been obtained through Wright Field[2]. An F6F-5 fighter was dived at a fixed ground target, and errors in keeping a Mk 8 fixed sight and a Mk 23 gyro sight on the target were photographically recorded. When all errors for all four pilots were averaged, an average error of 2.44 mils was obtained for the Mk8 sight and 1.24 mils for the Mk 23 sight. Air speeds varied between 170 and 310 knots. When all of the tracking data was divided into two speed groups, and elevation and deflection errors listed separately, the following average errors were determined.

	Elevation	Deflection
230 knots	0.95	1.52m
230 knots	1.09m	1.82m

[1]This is the effective value of "a". If ω in Eq. (11) represented angular velocity of the airplane rather than the line of sight, "a" would be replaced in (1 / a).

[2]Report "Experimental Determination of Tracking Inaccuracies of Fixed and Disturbed Computing Gunsights in Fixed Gun Fighter Aircraft", 24 August 1946, prepared by four Naval Officers under the direction of Dr. C. S. Draper, Instrumentation Laboratory, Massachusetts Institute of Technology.

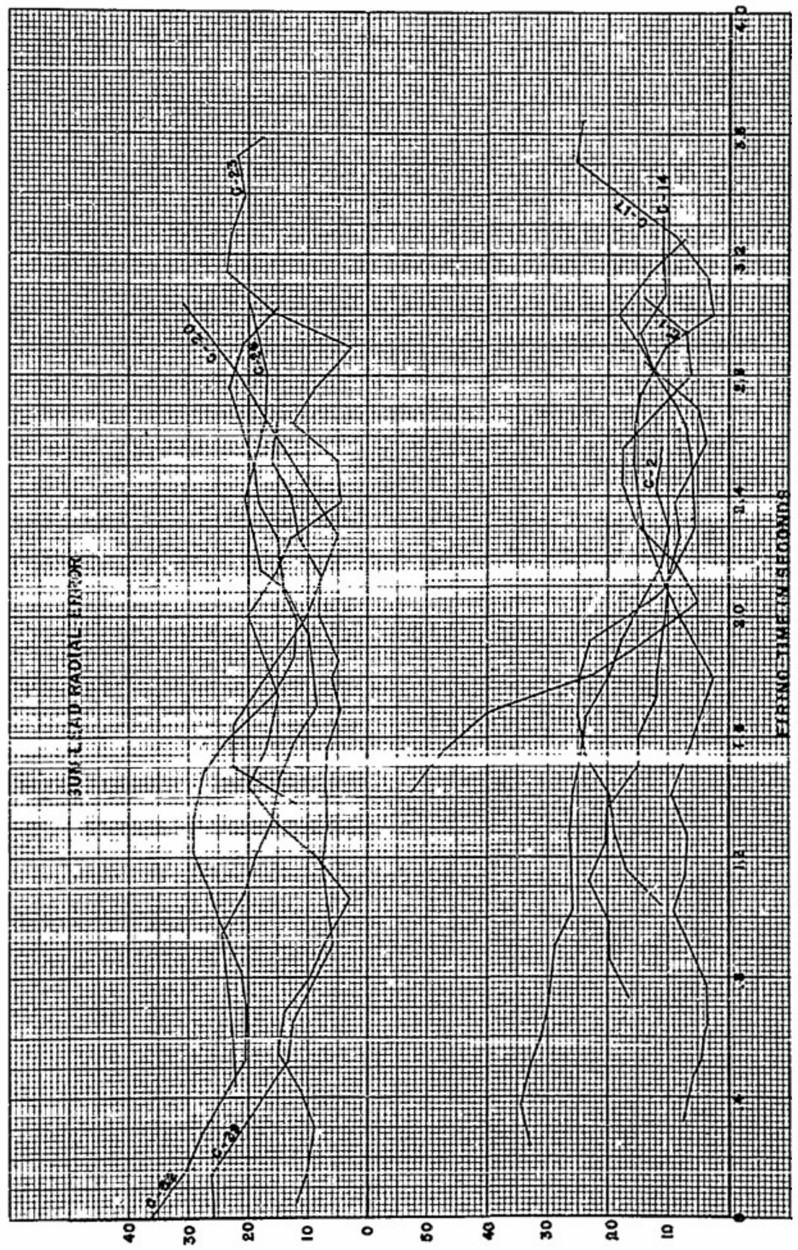


FIGURE 45

When the tracking data was separated according to angle of dive, the following table was obtained

	Elevation	Deflection
25°	0.82m	1.44m
25° - 35°	0.88m	1.39m
35°	1.45m	2.44m

The airplane is more difficult to control laterally because coordinated movements of ailerons and rudder are required, hence the large deflection errors. The report also comments that higher required control forces at high speeds increase tracking difficulty. Speed is also increased as dive angle increases, and it is observed in the report that there is increased difficulty in trimming the airplane in steep dives.

The tracking errors are less with the disturbed reticle sight, since the gyro tends to stabilize the reticle in spite of airplane and pilot irregularities. The guns, however, are fixed to the airplane, so that the effect of tracking errors on the gun errors would be about the same for the gyro sight as for the fixed sight if the amplification of error in the sight were about 2.0[1].

A study is being made of the frequency composition of the errors recorded in this report. Insufficient information is at hand at present to make rational estimates of the effect of tracking error on prediction error at a given range and angle of attack position when only time of flight in the computing sight is varied[2]. For this reason the contributions of mil tracking error to mil prediction error at a particular range will be taken as constant in succeeding computations of the present study, although times of flight for the various guns at the range chosen may vary somewhat.

Time of flight does affect contribution of range error to prediction error, in a manner which can be estimated. The lead required by the fighter is approximately, in the plane of action

$$\sin\lambda = (r\,\omega)/(v_f - v_a) = v_b\,(t_p/P)\sin\alpha \tag{26}$$

where the quantities in the above expression are defined in Fig. 46. Then if there is an error σ_r in range input (r) to the sight (assumed to be an angular rate x time sight) the corresponding mil error in pointing of the gun is

$$\sigma_{\lambda r} \cong (\lambda/r)\,\sigma_r \tag{27}$$

Now if σ_λ is any angular error at the instant of firing, the rounds travel a distance P to the target, hence the angular error results in a yard error P at the target. From Fig. 46 P is given by[3]

$$P\cos\lambda = r \,/\, v_b t_p \cos\alpha \tag{28}$$

---

[1]This is only the effect of tracking error. The gyro sight's main purpose is to compute accurately the lead which must be estimated by the pilot using the fixed sight, hence the overall accuracy of gun aim with the computing sight should be considerably better than that of the fixed sight.

[2]Range was set constant in the tests of the above report.

[3]tp is time of flight of the shell in these expressions.

For a given range at which the round is fired (r) the slower round travels a greater distance (in firing from the rear at the bomber) to impact the bomber, hence a given mil error results in a larger yard error at the target.

This effect also applies to deviations of the bomber's fire, but in the case to be considered, of short range fire to the rear, test computations indicate that it is sufficiently accurate to take P = r in computation.

The compounding of the contributions to prediction error of tracking error and ranging error are to be carried out for the fighter in the same fashion as for the bomber.

The dispersion of gun and ammunition are, however, considerably smaller for the fixed gun installation than for the bomber's turret.

b. Probability of Hitting: von Neumann's "diffuse target" concept considerably facilitates manipulation of the expressions for probability of hitting, and is considered sufficiently accurate for present computations. The following assumptions describe the method to be used.

Deviations are measured in a plane through the center of mass of the target and perpendicular to a trajectory through the center of mass, the x axis lying in the plane of action, and the y axis perpendicular to the plane of action.

A short burst is fired. As a result of tracking and ranging errors, the point at which the gun is aimed lies at distances h_x, h_y from the center of mass of the target. Individual rounds are, however, randomly distributed about this point with standard deviations in the two coordinates σ_x and σ_y. There are n rounds in the burst. The probability that any one round hits is small, but the expected number of hits is not necessarily small. Then if p is the probability that one round is a hit, the expected number of hits E is

$$E = np \tag{29}$$

and the probability of exactly "r" hits is, by the Poisson formula

$$H_r = (E^r/r!)\,e^{-E} \tag{30}$$

Following von Neumann[1], the probability that a round impacting at x, y is a hit is written as

$$e^{-(x/a_x)^2 - (y/a_y)^2} \tag{31}$$

where a_x and a_y can be related to the size of the target by $A_t = \pi a_x a_y$. Then with the center of aim at h_x, h_y, the probability that a round is a hit can he shown to be[2]

$$p = \frac{a_x}{(a_x^2 + 2\sigma_x^2)^{1/2}}\,\frac{a_y}{(a_y^2 + 2\sigma_y^2)^{1/2}}\,e^{-\frac{h_x^2}{a_x^2 + 2\sigma_x^2} - \frac{h_y^2}{a_y^2 + 2\sigma_y^2}} \tag{32}$$

---

[1]See appendix by J. von Neumann to BRL Report No. 241 "Optimum Spacing of Bombs of Shots in the Presence of Systematic Errors" by L. S. Dederick and R. H. Kent.

[2]Breit, G., BRL Report No. 549, "Diffusion of Fire Control Errors and Probability of a Preassigned Number of Hits".

If, in addition, the points of aim h_x, h_y observed over many bursts form normal distributions with standard deviations σ_{hx}, σ_{hy}, (but are constant for any single burst) the average probability that an error in aim h_x, h_y occurs and that exactly "r" hits are obtained in the burst fired at this erroneous point of aim, can be shown to be by methods developed in a prior memorandum report by one of the authors[1]

$$H_r = \sum_{m=0}^{\infty} \frac{(-1)^m}{r!\,m!} A^{r+m} \frac{1}{\left[1+B_x(m+r)\right]^{1/2}\left[1+B_y(m+r)\right]^{1/2}} \tag{33}$$

where

$$A = n \frac{a_x a_y}{(a_x^2 + 2\sigma_x^2)^{1/2}(a_y^2 + 2\sigma_y^2)^{1/2}} \tag{34}$$

$$B_x = \frac{2\sigma_{hx}^2}{a_x^2 + 2\sigma_x^2} \tag{35}$$

$$B_y = \frac{2\sigma_{hy}^2}{a_y^2 + 2\sigma_y^2} \tag{36}$$

Considering any single round of the burst, the "single shot probability" that it is a hit is

$$p_{ss} = p_o / \left[(1 + B_x)^{\frac{1}{2}} (1 + B_y)^{\frac{1}{2}}\right] \tag{37}$$

For the symmetric case where $a_x = a_y$, $\sigma_x = \sigma_y$, $\sigma_{hx} = \sigma_{hy}$, Eq. (33) reduces to the simpler form

$$H_r = \frac{1}{r!}\left(\frac{1}{B}\right)\left(\frac{1}{A^{1/B}}\right)\Gamma\left(r + \frac{1}{B}\right) I(u, p) \tag{38}$$

where

$$p = r - 1 + \frac{1}{B}\ ; \quad u = \frac{A}{\sqrt{r + (1/B)}}$$

where Γ is the complete Gamma function[2] and I refers to the incomplete Gamma function[3]. Eq. (38) has been evaluated for H_o and the results are plotted in Fig. 47. The probability of at least one hit is $1 - H_o$

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[1] Weiss, H. K., BRL Memorandum Report No. 448, "On the Attack of a Gun-Defended Bomber by a Rocket Bearing Fighter", 23, October 1946.

[2] Tabulated in "Tables of Functions", Jahnke, Emde, Dover Publications, 1943.

[3] Tabulated in "Tables of the Incomplete Γ -Function", Edited by Karl Pearson, Cambridge University Press, 1934.

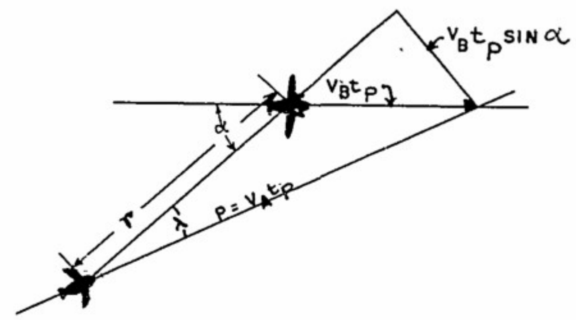


FIGURE 46

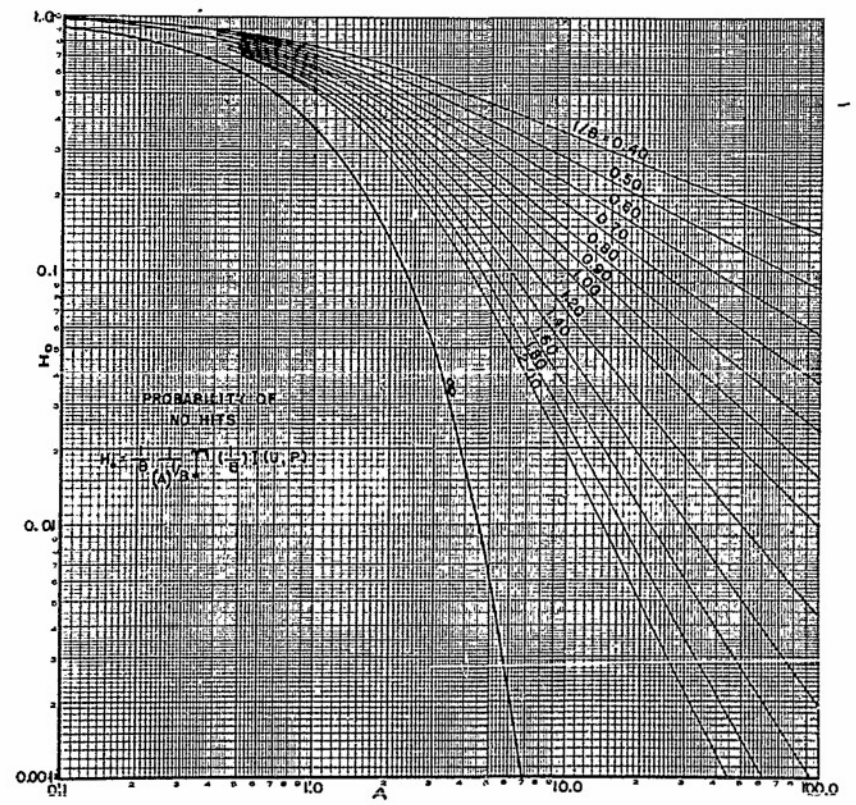


FIGURE 47

The more general case of determining the probability of exactly "r" hits when h_x and h_y vary during the burst has been solved by Dr. T. E. Sterne whose solution reduces to (38) for the case of perfect correlation between aiming errors during the burst. It is hoped that Dr. Sterne's development may be presented in a later report.

All rounds hitting the target are not lethal. If each hit may be considered an independent attempt to destroy the target (non-cumulative damage), and the probability that a hit is lethal is p_c, Eqs. (38) and (39) may be used to compute the probability of a kill

$$p_k = 1 - H_o \tag{39}$$

where, however, a new expression for A is taken instead of (34)

$$A = np_c p_o \tag{40}$$

For the general case where successive hits on the airplane cause related damage (for example a twin-engined airplane may be brought down by engine damage only if rounds strike both engines), the probability that "r" hits randomly distributed on the airplane will destroy it may be separately computed, by the methods described in the first part of this report, and combined with (33) to obtain the average probability that the airplane is destroyed by the burst

$$p_k = \sum_{r=1}^{n} p_{cr} H_r \tag{41}$$

where p_{cr} is the probability that exactly r hits will destroy the airplane and H_r is the probability of obtaining exactly r hits in the burst of n rounds. Graphs of p_{cr} against r are given in Part II of the present report (with slightly different notation) for various vulnerability conditions for the P-47 and B-25 aircraft.

8. Overall Assessment of Armament for a Bomber Turret: At the request of the Office of Chief of Ordnance, a brief comparison was made some time ago of the guns fired in the Optimum Caliber Program as armament for a bomber turret. Results of the computation were circulated for comment in memorandum form[1] and many helpful and informative comments were received, particularly from the Army Air Forces and the Navy. The following comparison follows the same lines as the original study, but is believed to be considerably more realistic, since the weight of the turret structure is now included, and the estimation of probability of hitting is related to specific characteristics of a fire control system. In the earlier memorandum probability of hitting was assumed inversely proportional to the square of time of flight, if only time of flight were varied, with range constant. This assumption is demonstrably untenable at the short ranges to be considered.

The following set of conditions is considered. A P-47 fighter attacks a bomber defended by a turret with an all-up weight (exclusive of fire control, tracking station, and operator) of 1500 lbs. The

[1]Memo. H. K. Weiss to Dr. T. E. Sterne, 22 Oct. 1946, subject: Armament for a Bomber Turret.

turret contains sufficient ammunition for a continuous duration of fire of 30 seconds.[1] When the fighter is at a range of 500 yards to the rear of the bomber the bomber fires a one second burst.[2] Cases of the fighter directly to the rear and 30° off the bomber's tail are included. Computations are to be made of the probability that the fighter is destroyed by this burst. The following assumptions are involved:

a. The number of rounds fired in the burst is obtained from Eq. (9), hence includes the effect of gun weight, rate of fire, ammunition weight, weight of turret structure.

b. The dispersion of gun plus turret is 4.25 mils and is the same for all turrets. This dispersion is superimposed on the aim error. The distribution of deviations from the point of aim is normal and circular.

c. The turret is controlled by a good fire control system, with a standard deviation of present position angular tracking error (lateral and vertical) of 3.0 mils and a standard deviation of radar range error of 20 yds. The amplification of the tracking error is obtained from Fig. 44. The equations of paragraph 7 are used to compute standard deviations of the point of aim as caused by the foregoing input errors. No bias errors of the computer are assumed, (hence the statement of a "good" fire control device).

d. Vulnerability figures for A-kills on the P-47 are taken from Table 3 of the Par II of this present report.

e. Since the target is a single-engined fighter subjected to a short burst, cumulative damage is not considered, and the probability of a kill is computed from Eqs. (33) and (40).

f. The bomber is assumed to be flying 450 m.p.h. and the fighter 500 m.p.h. Exterior ballistics of the rounds fired are as given in Appendix K.

Results of the computation are shown in Fig. 48. The 30mm Mk 108 gun firing H. E. ammunition is indicated (subject to the assumptions of the computation and the uncertainty of the basic data) to have a slightly higher probability of destroying the target than the other guns considered. The contributions of the various factors involved to this overall result may be seen by the figures of Table 10 which indicates intermediate stages of the computation. The quantity A,[3] the expected number of A-kills for no aim error, (Eq. 40) can be written with the aid of Eq. (8)

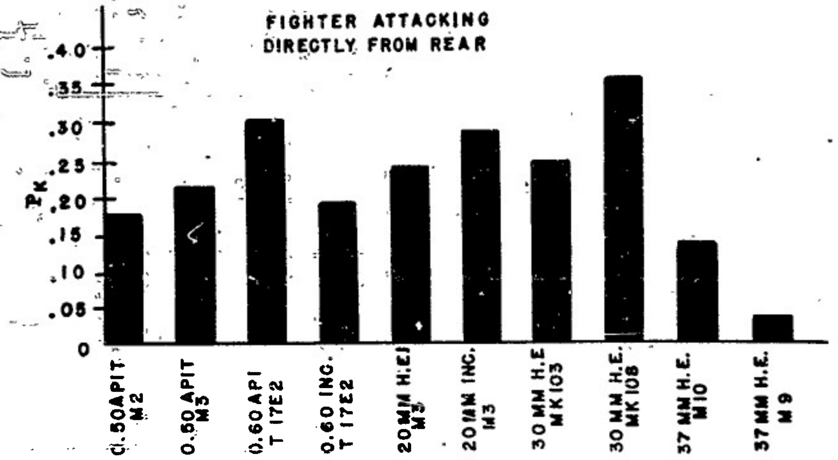
$$A = (t_b/T)\ \eta_a\ (p_c/w_a)\ (W_t - 100) \tag{42}$$

where t_b/T is the fraction of the total ammunition load fired in the burst, (1/30 for all guns), η_a is

[1]See also BRL Report 170, by H. H. Zornig and R. H. Kent, "A Method of Determining the Relative Efficiencies of Two Types of Aircraft Guns," and BRL Memo Report No. 221 by Major T. E. Sterne, "Comparison of Cal. 0.50, 0.60 and 20mm Flexible Armament for Bombers," both of which suggest equal weight-equal time comparisons for armament.

[2]The reason that this single short range was chosen is that sufficient damage information for computations at other ranges is not available at the time of preparation of this report. As described in Part I of this report, information is being obtained at other ranges and should be availabe shortly.

[3]The probability of a kill increases monotonically with A for constant B.



COMPARISON OF ARMAMENT FOR 1500 LB. BOMBER TURRET. PROBABILITY OF DESTROYING P-47 FIGHTER AT 500 YD. RANGE BY 1 SEC. BURST (1/30 TOTAL AMMO. LOAD)

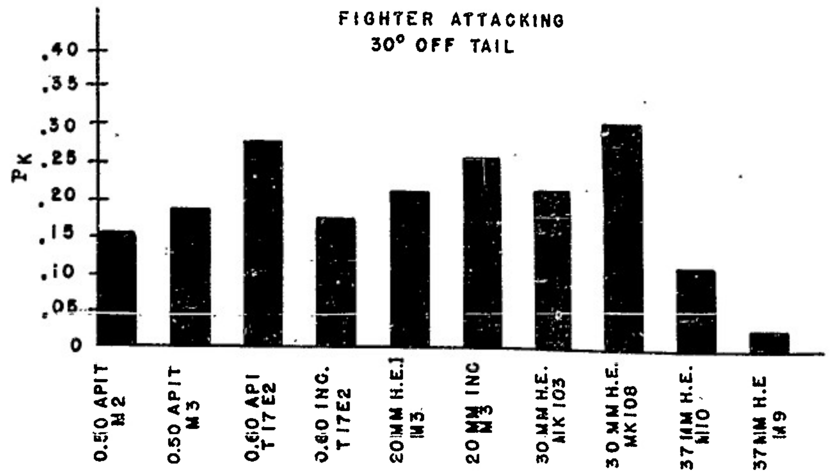


FIGURE 48

"armament efficiency", the fraction of the turret weight allotted to ammunition, and p_c/w_a is the probability that a hit by a single round causes an A-kill divided by the weight of one round complete with link. The quantity B used in computing overall probability of a kill depends only on aim errors, dispersion and target size. Its effect can be indicated by computing the single shot probability of a hit. Table 10 shows the separate factors of (42), and also the single shot probability of a hit.

Observing the column (p_c/w_a) in Table 10, it will be noted that the 30mm round has a higher probability of kill per pound of round weight than any other round. This high terminal ballistic efficiency gives the round a great initial advantage over the other rounds. The column "Armament Efficiency" indicates that the high rate of fire and comparatively light weight of the gun, together with its low muzzle energy, permit almost half of the turret weight (.47) to be allotted to ammunition. Only the Cal. 0.50 M3 gun has an equally high armament efficiency, but the probability of an A-kill per pound of the Cal. 0.50 API-T round is only one quarter as great as the probability per pound of the 30mm. Finally, since the firing is to the rear at

TABLE 10

Gun	Ammo	(pc/wa) A-Damage	Armament Efficiency	Single Shot Probability Of Hitting: Pss O Degrees	Pss 30 Degrees
0.50 M2	API-T M20	.063	.377	.181	.162
0.50 M3	API-T M20	.063	.471	.181	.162
0.60 T17E2	API T39	.118	.361	.195	.179
0.60 T17E2	INC T36E2	.067	.361	.195	.179
20MM M3	HEI M9	.097	.376	.171	.154
20MM M3	INC M96	.123	.376	.171	.154
30MM MK103	HE	.130	.315	.158	.141
30MM MK108	HE	.216	.471	.121	.103
37MM M10	HE M54	.135	.160	.137	.120
37MM M9	HE M54	.103	.109	.165	.145

fairly short range in the cases considered, the 30mm gun is not greatly penalized in probability of hitting ~~for its low muzzle velocity.~~ The Cal. 0.60 gun with high muzzle velocity indicates the highest probability of hitting which, together with fairly high probability per pound and average armament efficiency combines to show an overall probability of kill slightly less than that of the 30mm.

The fact that several of the guns and ammunitions show nearly the same overall probability of kill in Fig. 48 means that a clear choice among them cannot be made on so brief an examination of their characteristics. As future information is obtained on firings at longer ranges, it is believed that the difference between guns will increase to the point where such a choice can be made and substantiated. The present computations are to be considered as illustrative of a method rather than as giving a final result.

9. Overall Assessment of Armament for a Fixed Gun Fighter:

a. Tactical Assumptions

A thorough comparison of alternate types of guns and ammunition as armament for a fixed gun fighter must involve the possibility of various types of attacks, closing speeds, and must consider the defensive armament of the target being attacked. In particular, as described in paragraph 6, the optimum opening and closing range for the fighter, and the optimum number of guns for a given weight of armament installation must be determined. Such complete analysis will require the results of firings at other ranges than those which have been completed in the Optimum Caliber program to date, and will be carried out as such data are made available.

For the present, the following simpler situation will be considered. The fighter is assumed to have attained a position 500 yards to the rear of the bomber, and about 20° off the bomber's tail. Its fire is directed at the bomber from about 13° above the bomber. The bomber is a B-25 considered here since the Optimum Caliber firings apply directly. The extension to multi-engined jet bombers will be carried out in later reports.

The fighter speed is assumed to be 450 m.p.h. and the bomber speed 400 m.p.h. Presented area of the bomber is 33.3 yds. Ammunition dispersion for the fighter's guns is assumed to have 2.0 mils standard deviation for all the guns considered. Later analysis will employ the proper variation of dispersion with caliber. The aiming error perpendicular to the plane of action is assumed to be 3.0 mils. The deflection error in the plane of action is assumed to be 4.5 mils plus the deflection error resulting from 20 yards error in range (good radar range). The deflection error varies with shell velocity, as does the yard error at the target corresponding to the assumed mil errors at the fighter. The aim errors are assumed constant during the attack, but randomly distributed with the above standard deviations across attacks.

b. Bomber Vulnerability

The bomber is assumed to have main fuel cells full and auxiliary cells empty. Two types of bomber vulnerability are considered.

1. Singly Vulnerable Bomber: The bomber can be shot down by structural damage, by fuel cell ignition, by stopping one or both engines, or by killing one or both pilots.

2. "Multiply" Vulnerable Bomber: The bomber can be shot down by structural damage, by fuel cell ignition, by stopping both engines, or by killing both pilots.

An abbreviated form of the method described in Part II of this report will be employed to take care of the "multiply" vulnerable case. The procedure is as follows:

Let p be the probability that a single round hits the airplane, and assume that any part of the airplane is as likely to be hit as any other part. Let p_c with appropriate subscript indicate the probability that if a round strikes the airplane it will disable a particular component. Only "A" damage will be considered in the present computations. Let E represent the expected number of lethal hits from the burst. Then, in general, the expected number of lethal hits on a component is

$$E = npp_c \qquad (43)$$

Let E_s, E_e, E_p, E_t represent expected numbers of lethal hits on singly vulnerable components, one engine, one pilot, and the whole airplane, respectively. It follows that

$$E_t = E_s + 2E_e + 2E_p \qquad (44)$$

(Note that a hit lethal to an engine or a pilot is not necessarily lethal to the airplane).

The probability that no singly vulnerable component receives a lethal hit, is, assuming individual probabilities small, but E not necessarily small,

$$e^{-E_s} \qquad (45)$$

The probability that one engine survives is e^{-E_e}, the probability that it does not survive is $1 - e^{-E_e}$, the probability that both engines are killed as $(1 - e^{-E_e})^2$, the probability that both engines are killed is $(1 - e^{-E_e})^2$, and the probability that both engines are not killed is

$$1 - (1 - e^{-E_e})^2 \qquad (46)$$

Similarly the probability that both pilots are not killed is

$$1 - (1 - e^{-E_p})^2 \qquad (47)$$

Since the above three items represent the possible ways of destroying the airplane, the probability that it is not destroyed is their product.

$$P_s = e^{-E_s}\left[1 - (1 - e^{-E_e})^2\right]\left[1 - (1 - e^{-E_p})^2\right] \qquad (48)$$

which can be simplified by letting

$a_e = 2E_e/E_t$ = fraction of expected lethal hits on plane received by both engines

$a_p = 2E_p/E_t$ = fraction of expected lethal hits received by both pilots

Then 48 becomes

$$P_s = e^{-E_t}(2e^{.5a_eE_t}-1)(2e^{.5a_eE_t}-1) \qquad (49)$$

Now consider the probability of hitting the airplane, p. Assume circular normal distributions of gun dispersion and aiming error. Then following the method of paragraph 7-c and the references given therein,

$$\bar{p} = p_o e^{-Bh^2/2\sigma_h^2} \tag{50}$$

where h is constant for the burst but normally distributed across bursts. Then if the probability that h takes a value between h and $h + dh$ is written

$$(1/\sigma_h^2)\, h e^{-h^2/2\sigma_h^2}\, dh \tag{51}$$

the probability that E_t assumes a value between E_t and $E_t + dE_t$ is, making the transformation suggested by Sterne,

$$p(E_t)\, dE_t = 1/(BA^{1/B})\, E_t^{1/B-1}\, dE_t \tag{52}$$

and the average value of p_s is

$$\bar{p}_s = \int_0^A p_s p(E_t)\, d E_t \tag{53}$$

Now the general term of p_s is

$$e^{-E_t b} \tag{54}$$

and making a change of variable $E_1 = E_t b$ in (53), the general term is

$$\frac{1}{B(Ab)^{1/B}} \int_0^{Ab} e^{-E_1} E_1^{1/B-1}\, d E_1 \tag{55}$$

which has the solution given as Eq. (38) if A is replaced by Ab. Hence Fig. 47 can be used to obtain the individual terms of (53), and the results summed to give $\bar{p}_s$. The probability that the twin-engined bomber is destroyed by the burst is then

$$p_k = 1 - \bar{p}_s \tag{56}$$

The distribution of aiming errors is not circular normal, as derived from the assumptions at the head of this paragraph. An approximate value of B, replacing the elliptical distribution by an approximate circular distribution will be employed, obtaining

$$B = (B_x B_y)^{1/2} \tag{57}$$

c. Assumed Fighter Types: Two types of fighter are considered. The one-pass fighter is assumed to carry a total armament weight (guns plus ammunition plus associated structure) of 1000 lbs and to use up all its ammunition in one pass. The time required for the fighter to attain 50% (and in one case 90%) probability of destroying the bomber is computed. The multiple pass fighter is arbitrarily assumed to carry 3 times the amount of ammunition required to attain 50% probability in a single pass, and has a total armament weight of 1500 lbs.

The theory of ammunition requirements for a multiple-pass fighter is in an embryonic state at the time of writing, but the following brief discussion is offered. Suppose a fighter carries N rounds of ammunition. It attacks its first bomber and opens fire. As each round reaches the bomber there is a probability that the bomber will be destroyed, possibly by this round, possibly by the cumulative effect of all rounds up to the round being considered. If the bomber is destroyed, the fighter breaks off at once and seeks a second target. There is, of course, also the probability that the fighter is destroyed, which must be considered as well.

The fighter continues to attack new targets until its mission is completed, or it runs out of ammunition. For the simplest case where each round represents an independent attempt at destroying the target, the probability of destroying M targets can be shown to be

$$P_{kM} = 1 - H_o - H_1 - \cdots - H_M \tag{58}$$

for $M \leq N$ where H_r is the probability of obtaining exactly "r" lethal hits. The first lethal hit accounts for the first bomber, the second for the second, etc. The fighter may return to base with unexpended ammunition, which accounts for the fact that P_{kM} is equivalent to the probability of "at least" M lethal hits.

d. Results: Fig. 49 shows the time required for the one-pass fighter to attain 50% and 90% probability of a kill against the singly vulnerable bomber. Fig. 50 shows the reciprocal of this time, a form of presentation which is more convenient for visual examination of the figures. This reciprocal of killing-time is roughly equivalent to the rate of increase of probability of a kill with firing time.

Fig. 51 shows time required for the one-pass fighter to attain 50% probability of a kill against the multiply-vulnerable bomber and Fig. 52 shows the reciprocal of this time.

Fig. 53 shows time required for the multiple-pass fighter to attain 50% probability of a kill against the multiply vulnerable bomber, and Fig. 54 shows the reciprocal of this time.

In these figures the type of ammunition is identified on a line with the caliber, and the gun model listed below it.

Note that the order of effectiveness of the various calibers and ammunitions does not change significantly in the three sets of conditions considered. The 30mm gun Mk-108 firing HE ammunition shows the shortest firing time to reach the chosen probabilities of obtaining an A-kill on the bomber for a given total armament weight. It must be remembered, however, (see Appendix K, Exterior Ballistics) that the Mk-108 rounds would not reach the bomber from a range of 1000 yards.

The figures indicate that from 500 yards and the chosen angle of attack the 20mm Incendiary round is more effective than the HE round. On the other hand, the Cal. 0.60 API round appears more effective than the Cal. 0.60 Incendiary round, from this angle. A discussion of the effect of angle of attack on terminal effect of the various rounds will be found in Parts I and II of this report.

A discussion of the manner in which the various parameters affect the results illustrated in the preceding figures is facilitated by reference to Table 11. The column P_{cA}/w_a shows the "probability per pound" of a hit causing "A" damage if the whole airplane were singly vulnerable. The amount by which this quantity is reduced by duplicated components (engines and pilots) is indicated by the table of f_{sv} (fraction of total vulnerable area composed of duplicated components). Note that as the size of round increases, the proportion of the area vulnerable to a single hit increases. This tends to make the large caliber rounds more effective. The 30mm rounds show the highest "probability per pound" for A-damage, and almost half the vulnerable area of the airplane is "singly vulnerable" to these rounds.

TABLE 11

Gun	Ammo	$\frac{P_cA}{w_A}$	f_{sv}	50% N_r	90% N_r	τ^2 (sec)
0.50 M2	API-T M20	.037	.000	1.4	6.0	19.9
0.50 M3	API-T M20	.037	.000	1.4	6.0	14.0
0.60 T17E2	API T39	.036	.214	1.3	5.6	19.9
0.60 T17E2	INC T36E2	.017	.420	1.3	5.6	19.9
20MM M2	HE1 M97	.019	.436	1.4	6.3	21.1
20MM M2	INC M96	.045	.252	1.4	6.3	21.1
20MM M3	HE1 M97	.019	.436	1.4	6.3	16.8
20MM M3	INC M96	.045	.252	1.4	6.3	16.8
30MM MK108	HE	.104	.448	1.9	11.5	13.4
30MM MK103	HE	.063	.448	1.5	6.9	24.4
37MM M10	HE M54	.056	.534	1.5	7.3	48.1
37MM M9	HE M54	.043	.534	1.4	6.3	75.0
75MM	HE	.045	1.000	1.5	6.7	121.9

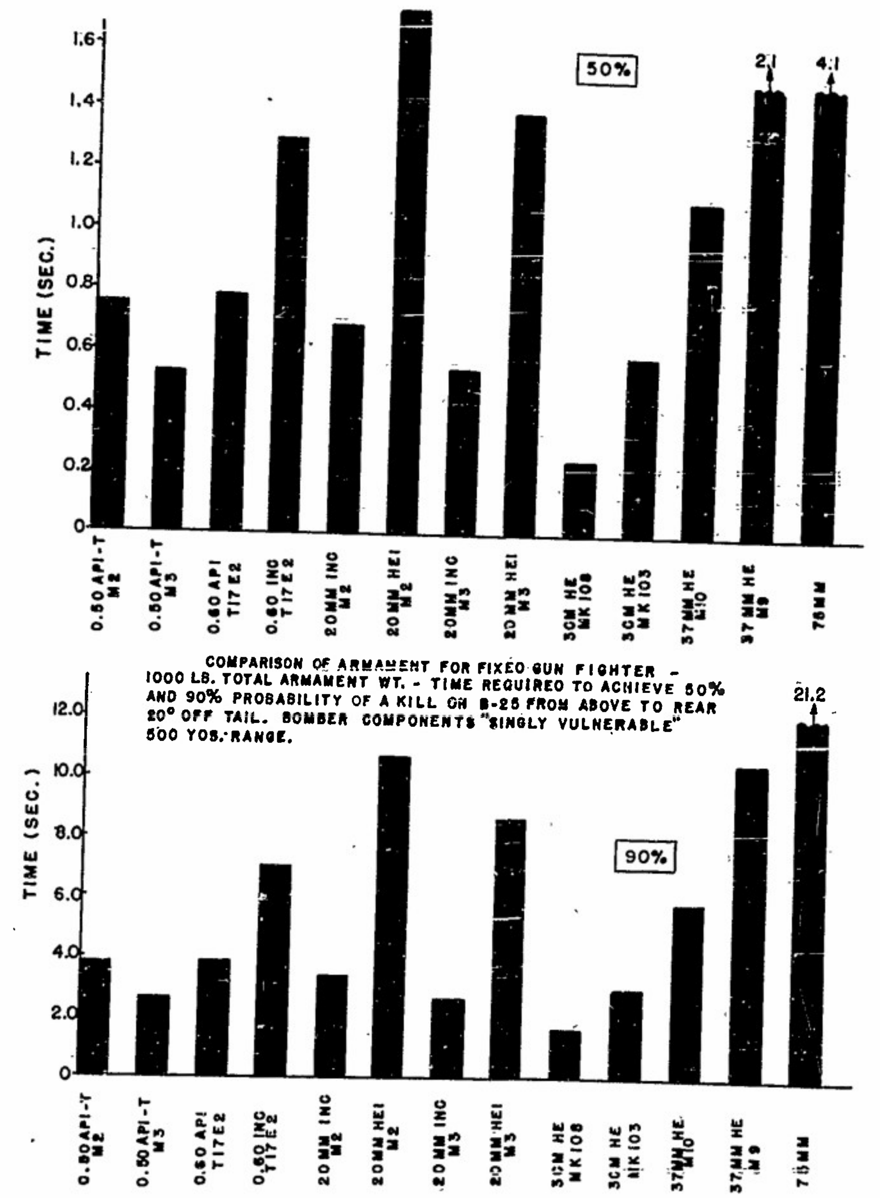


FIGURE 49

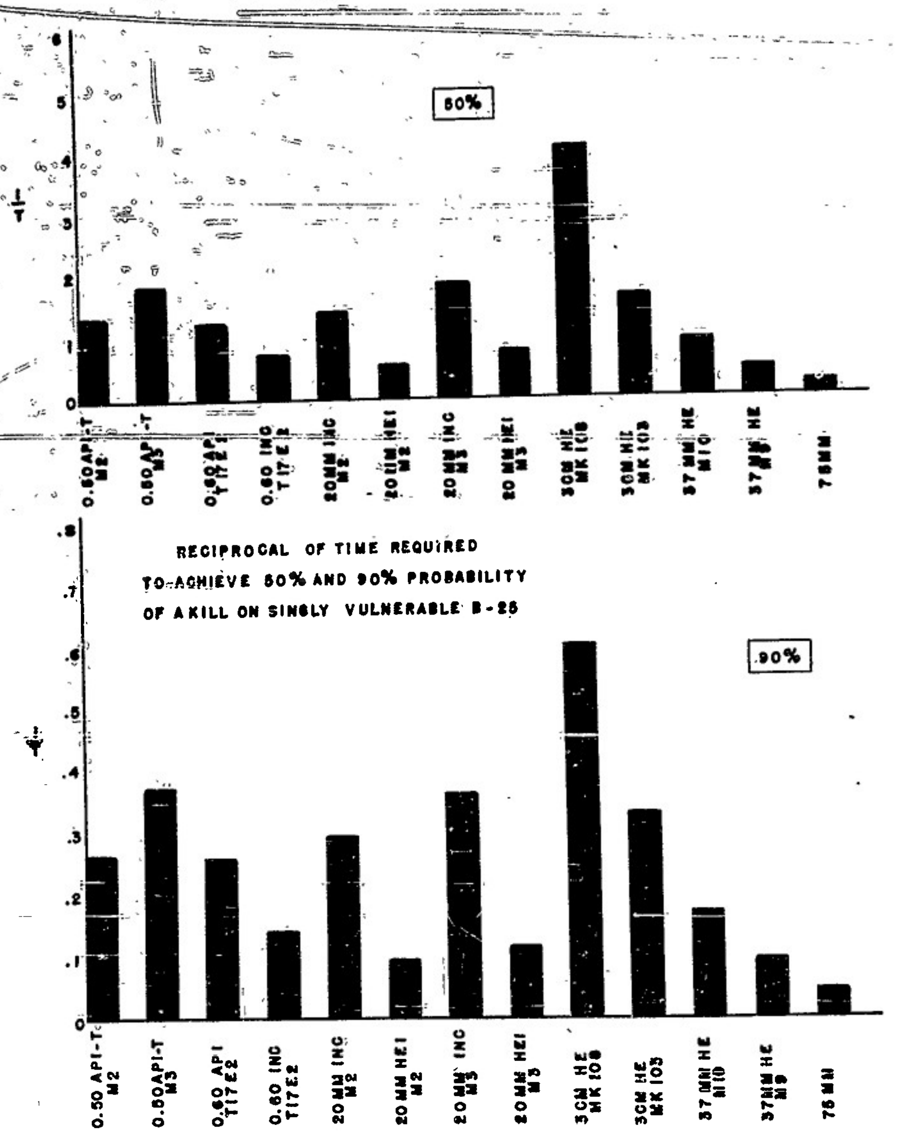


FIGURE 50

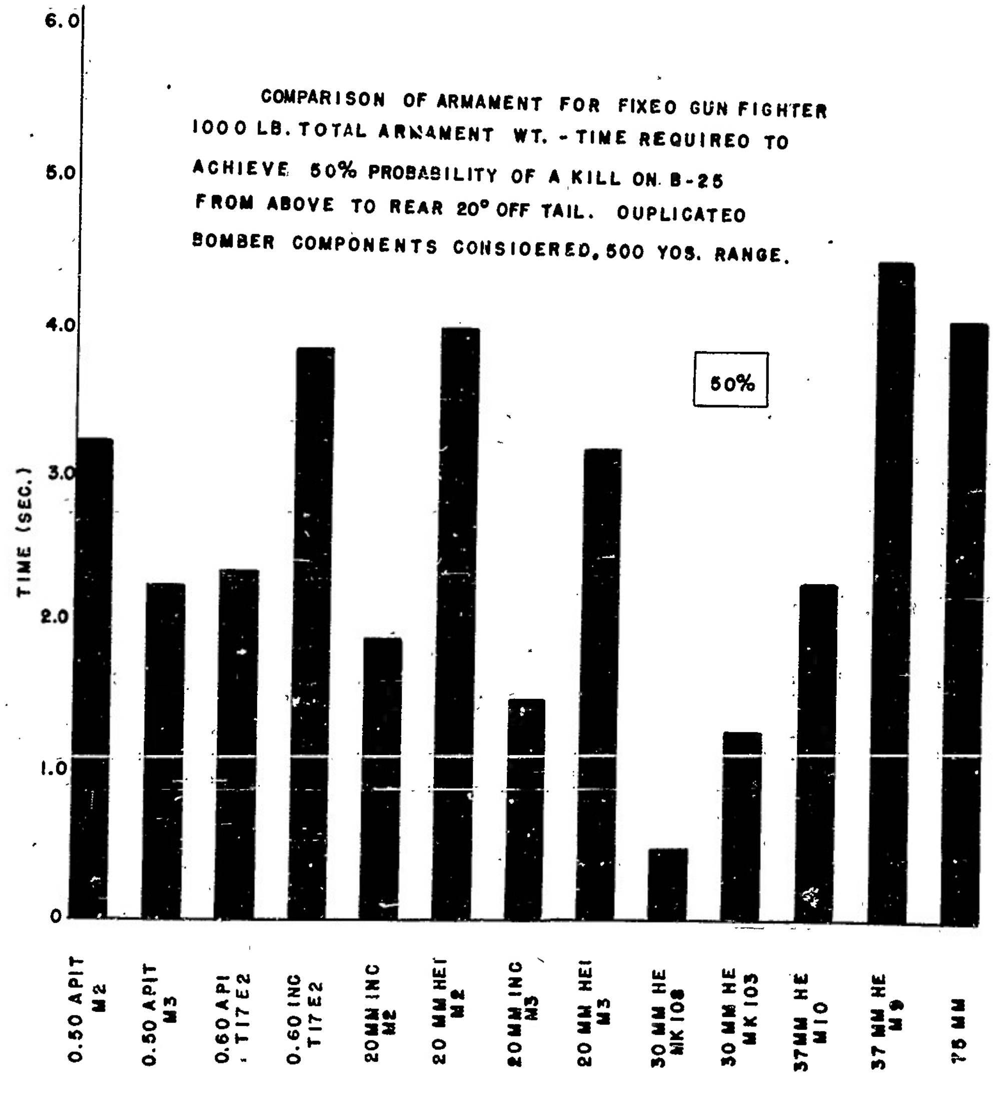


FIGURE 51

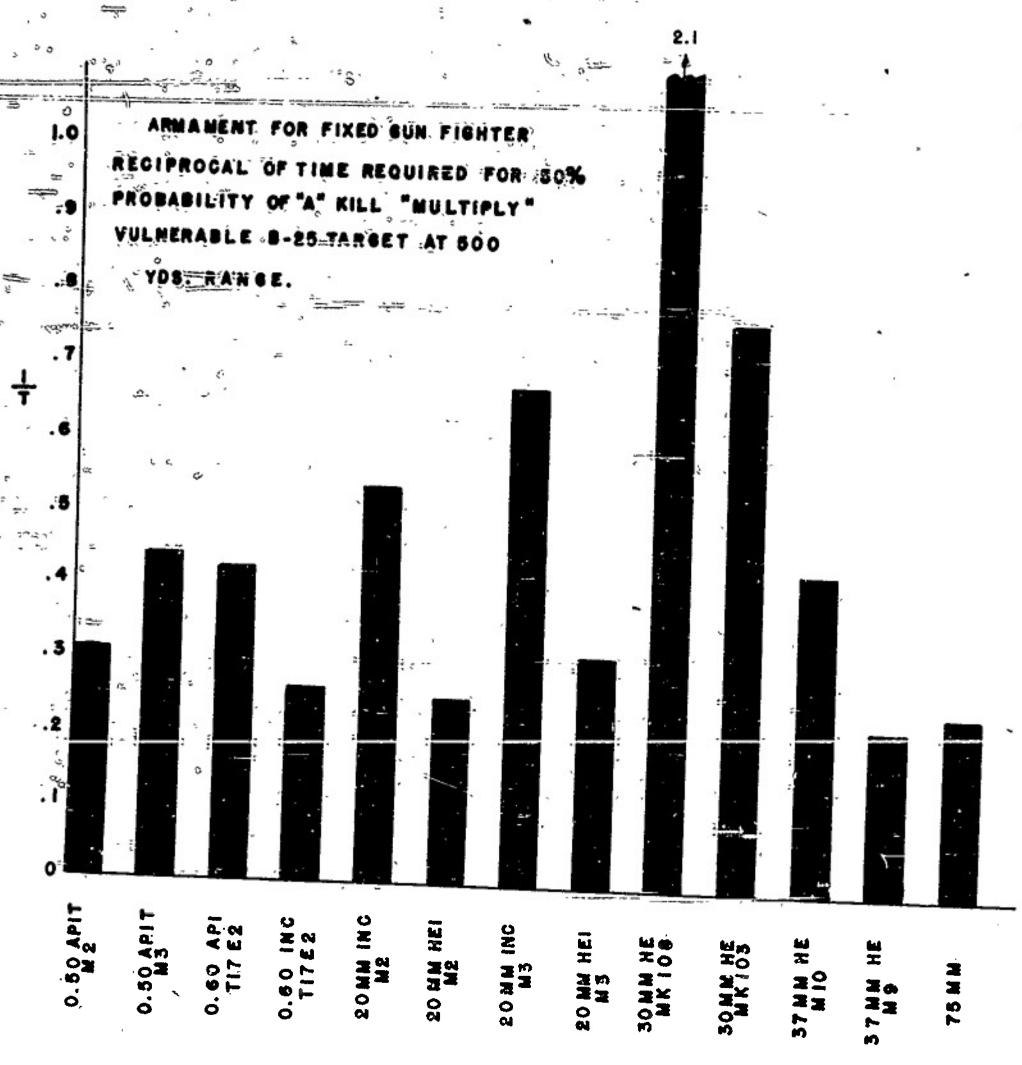


FIGURE 52

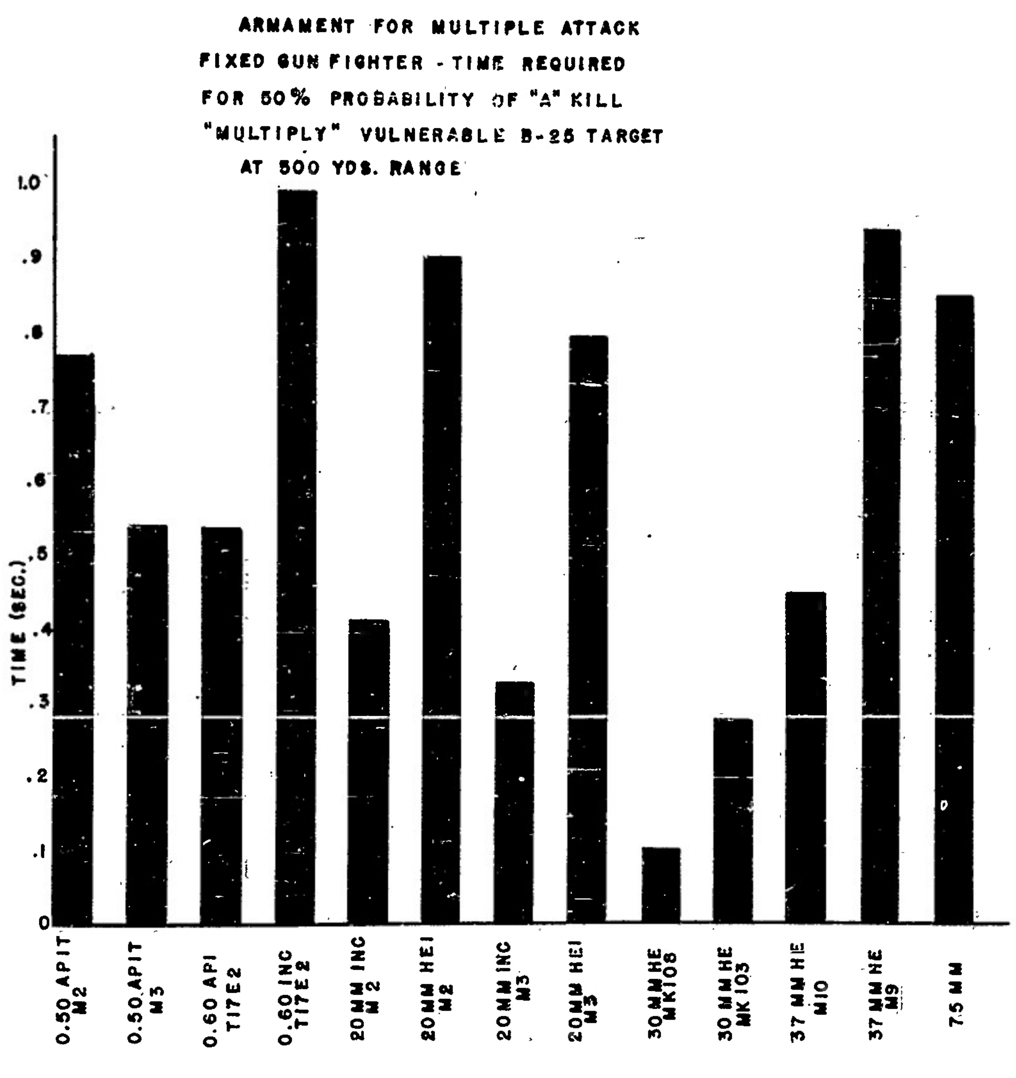


FIGURE 53

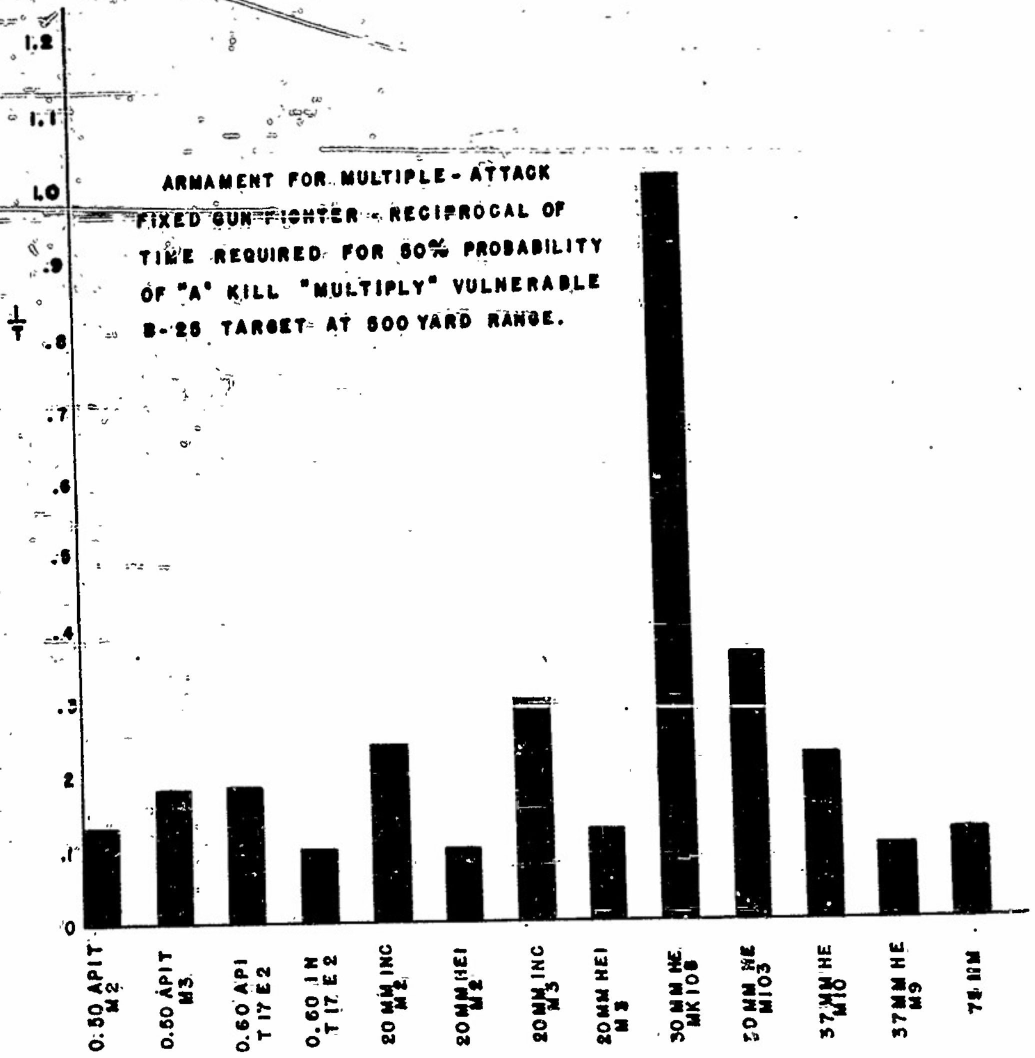


FIGURE 54

The effect of probability of hitting is shown in the columns headed n_r. n_r is the number of rounds which must be fired to obtain 50% or 90% probability of a hit under the assumed values of aim error and dispersion. Many times this number of rounds must be fired to obtain the same probability of a lethal hit. The comparatively small numbers listed under n_r indicate that the assumed values of aim errors are considerably smaller than existing fire control devices permit. It should again be remembered, however, that this chosen angle of attack and range do not present a particularly difficult problem to the fire control system. For 90% probability of hitting, there is about a 2:1 difference between the Cal. 0.60 and the 30mm guns under the assumed conditions.

The final column is of τ_2, the time the gun requires to shoot its own weight (plus mounting weight) in belted ammunition. If all other quantities (p_{ca}/w_a, f_{sv}, and n_r) were equal, the time required for a gun to attain a particular probability of a kill would be proportional to τ_2, (see Eq. 10). Hence the time required for a kill is directly proportional to the gun weight and inversely proportional to its rate of fire. The Cal. 0.50 gun M3 and the 30mm gun Mk 103 both show excellent efficiency as machines for rapidly projecting large weights of ammunition, but the terminal effect of the Cal. 0.50 rounds is comparatively small. The 30mm rounds, therefore, with their high "probability per pound" fired from a gun with low weight and high rate of fire, give a very high overall effectiveness to the armament installation employing 30mm guns, as indicated in the figures.

Comparing the charts for killing time against the "singly vulnerable" bomber with those for the "multiply vulnerable" bomber, it will be noted that the relative standing of the heavier rounds improves when two engines or two pilots must be killed. This is a result of the fact that the heavier rounds do relatively more structural damage and have higher probability of igniting the fuel cells than do the small rounds. If the pilots had increased armor protection and the airplane had four engines, the effectiveness of rounds smaller than 30mm would drop significantly in the comparison.

10. Conclusion: In closing this preliminary study it is necessary to emphasize again that the figures in this memorandum report represent comparisons of the guns and ammunition of the Optimum Caliber Program in highly limited tactical situations. The conditional probabilities that hits are lethal have, moreover, been taken from the data reduced to date in the Optimum Caliber Program, while additional data, already available from firings completed since 1 December 1946 may change the probabilities somewhat while increasing their accuracy. The methods of analysis of overall effectiveness are themselves subject to refinement and extension as the study progresses. The authors desire therefore, to submit this report primarily as a summary of the experimental results and methods of attack to date, as an indication of the lines of thought being pursued, and as a review of the relative standing of the ammunition and gun types to date. Only when data are available over a wide range of tactical situations and the possibilities of improving both guns and ammunition over present standards have been considered can clear recommendations be made regarding an "Optimum Caliber". It is anticipated that succeeding reports will bring the analysis closer to this desired objective.

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APPENDICES

Appendix A

FIRINGS COMPLETED BETWEEN MAY 1946 AND 1 DECEMBER 1946

In the following table the line of fire is designated by the angle θ, which is the angle in a horizontal plane between the line of fire and the longitudinal axis of the fuselage and the angle ϕ, which is the angle that the plane of the wings makes with the horizontal. The plane of the wings is defined as the plane passing through the leading and trailing edges of the wing. Leading edge up will be referred to as a positive angle for ϕ and leading edge down as negative. It is not necessary to distinguish between positive and negative values of θ because of the symmetry in the horizontal plane about the longitudinal axis.

In general, impact firings have been conducted from both the front and the rear against the target aircraft. In either case the angle θ was 20° and the angle ϕ was usually either 13° or -13°.

A few firings conducted after December 1, 1946 have been included in this table when it was possible by their inclusion to present complete results on a firing phase.

TABLE A1

COMPLETED FIRINGS AS OF DECEMBER 1, 1946

A. Fuel Tanks.

1. Target: P-38 Fuel Cells, Rear Above JP-1, Kerosene Filled

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	25	P-41261
.50	Inc M23	.50 Mann Barrel (36" long)	500	20	13	18	P-41262
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	17	P-41264
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	13	P-41263
20mm	HEI M97	20mm AC M3	500	20	13	16	P-41269
20mm	HEI M97	20mm AC M3	500	20	13	15	P-41280
20mm	Inc M96	20mm AC M3	500	20	13	15	P-41268
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	7	P-41270

2. Target: P-38 Fuel Cells, Rear Above, Gasoline Filled

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	15	P-41074
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	12	13	P-41247
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	1	P-41078
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	1	P-41079
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	12	P-41087
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	11	P-41248
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	4	P-41089
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	25	P-41250
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	2	P-41265*
20mm	HEI M97	20mm AC M3	500	20	13	5	P-41091
20mm	HEI M97	20mm AC M3	500	20	13	10	P-41090
20mm	HEI M97	20mm AC M3	500	20	13	9	P-41253
20mm	Inc M96	20mm AC M3	500	20	13	4	P-40499
20mm	Inc M96	20mm AC M3	500	20	12	14	P-41255
3cm	HE Mk108	3cm Mk108 (Ger.)	200	20	13	8	P-41237
3cm	HE Mk108	3cm Mk108 (Ger.)	200	20	13	6	P-41256
37mm	HE M54	37mm AC M9	500	20	13	11	P-41246
37mm	HE M54	37mm AC M9	500	20	13	5	P-41260

3. Target: B-25 Fuel Cells, Rear Above, Gasoline Filled

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	21	P-40496
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	28	P-41050
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	7	P-40497
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	18	P-41051
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	2	P-40498
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	8	P-41053
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	6	P-41054
20mm	HEI M97	20mm AC M3	500	20	13	9	P-41055
20mm	HEI M97	20mm AC M3	500	20	13	2	P-41056
20mm	Inc M96	20mm AC M3	500	20	13	2	P-41070
20mm	Inc M96	20mm AC M3	500	20	13	8	P-41073

* Partially Filled Cells

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	4	P-41071
37mm	HE M54	37mm AC M9	500	20	13	4	P-41072

4. Target: P-59 Fuel Cells, Rear Above, Kerosene Filled

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	13	P-41272
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	11	P-41271
20mm	HEI M97	20mm AC M3	500	20	13	7	P-41275
20mm	Inc M96	20mm AC M3	500	20	13	13	P-41274

B. Engine

1. Target: P-38 Engines, Front Below, Single Shot

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	8	P-40501
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	11	P-40502
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	10	P-40503
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	13	P-40504
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	2	P-41002
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	14	P-41003
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	4	P-41004
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	4	P-41001
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	8	P-41005
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	9	P-41006
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	14	P-41007
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	4	P-41008

2. Target: P-38 Engines, Rear Above, Single Shot

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	4	P-40505
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	11	P-40506
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	6	P-40509
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	4	P-40510
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	4	P-40518
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	3	P-40996
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	9	P-40507
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	8	P-40508
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	10	P-40997
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	6	P-40998
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	5	P-40999
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	2	P-41000

3. Target: B-25J Engine, Front Below, Single Shot

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Line of Fire ∅ deg.	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	9	P-40432
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	7	P-40433
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	9	P-40467
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	20	P-40468

3. Target: B-25J Engine, Front Below, Single Shot (cont'd)

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	∅	Total Hits	APG F.R.
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	14	P-40434
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	9	P-40435
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	11	P-40469
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	8	P-40470
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	12	P-40436
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	6	P-40437
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	10	P-40471
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	17	P-40472
20mm	HEI M97	20mm AC M3	500	20	13	6	P-40441
20mm	HEI M97	20mm AC M3	500	20	13	3	P-40442
20mm	HEI M97	20mm AC M3	500	20	13	9	P-40473
20mm	HEI M97	20mm AC M3	500	20	13	4	P-40474
20mm	Inc M96	20mm AC M3	500	20	13	3	P-40439
20mm	Inc M96	20mm AC M3	500	20	13	12	P-40440
20mm	Inc M96	20mm AC M3	500	20	13	7	P-40475
20mm	Inc M96	20mm AC M3	500	20	13	8	P-40476
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	4	P-40450
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	6	P-40451
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	6	P-40452
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	4	P-40454
37mm	HE M54	37mm AC M9	500	20	13	3	P-40438
37mm	HE M54	37mm AC M9	500	20	13	[illegible]	P-40443
37mm	HE M54	37mm AC M9	500	20	13	1	P-40444
37mm	HE M54	37mm AC M9	500	20	13	4	P-40483
37mm	HE M54	37mm AC M9	500	20	13	2	P-40484
75mm	HE M48	75mm AC T13E1	100	20	13	1	P-40449
75mm	HE M48	75mm AC T13E1	100	20	13	1	P-40485
75mm	HE M48	75mm AC T13E1	100	20	13	1	P-40486
105mm	HE M1	105mm T7	100	20	13	1	P-40448

4. Target: B-25J Engines, Front Above, Single Shot

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	3	P-41080
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	10	P-41081
20mm	HEI M97	20mm AC M3	500	20	13	6	P-41084
20mm	HEI M97	20mm AC M3	500	20	13	5	P-41083
20mm	Inc M96	20mm AC M3	500	20	13	5	P-41085
20mm	Inc M96	20mm AC M3	500	20	13	5	P-41086

5. Target: B-25 Engines, Rear Below, Single Shot

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	7	P-41011
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	16	P-40515
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	4	P-41009
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	2	P-41010
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	4	P-41012
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	2	P-41013
20mm	HEI M97	20mm AC M3	500	20	13	3	P-41014
20mm	HEI M97	20mm AC M3	500	20	13	8	P-41015

5. Target: B-25 Engines, Rear Below, Single Shot (cont'd)

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	∅	Total Hits	APG F.R.
20mm	Inc M96	20mm AC M3	500	20	13	9	P-41016
20mm	Inc M96	20mm AC M3	500	20	13	9	P-41017
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	1	P-41023
3cm	He Mk108	3cm AC Mk108 (Ger.)	200	20	13	2	P-41024
37mm	HE M54	37mm AC M9	500	20	13	3	P-41025
37mm	HE M54	37mm AC M9	500	20	13	3	P-41026
75mm	HE M48	75mm AC T13E1	100	20	13	1	P-41027
75mm	HE M48	75mm AC T13E1	100	20	13	2	P-41028
105mm	HE M1	105mm AC T7	100	20	13	1	P-41029
105mm	HE M1	105mm AC T7	100	20	13	2	P-41030

6. Target: B-25 Engines, Rear Above, Single Shot

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	4	P-40082
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	5	P-40087
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	6	P-40085
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	6	P-40086
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	7	P-40091
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	2	P-40092
20mm	HEI M97	20mm AC M2	500	20	13	3	P-40093
20mm	HEI M97	20mm AC M2	500	20	13	4	P-40094
20mm	Inc M96	20mm AC M2	500	20	13	2	P-40097
20mm	Inc M96	20mm AC M2	500	20	13	2	P-40098
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	1	P-40101
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	1	P-40102
37mm	HE M54	37mm AC M9	500	20	13	2	P-40099
37mm	HE M54	37mm AC M9	500	20	13	4	P-40100
75mm	HE M48	75mm AC T13E1	100	20	13	2	P-40105
75mm	HE M48	75mm AC T13E1	100	20	13	2	P-40110
105mm	HE M1	105mm AC T7	100	20	13	1	P-40106
105mm	HE M1	105mm AC T7	100	20	13	1	P-40111

7. Target: B-25 Engines, Front Below, Burst Fire

.50	API-T M20	.50 AC HB M2	500	20	0	21	P-40420
.50	API-T M20	.50 AC HB M2	500	20	13	25	P-40456
.50	API-T M20	.50 AC HB M2	500	20	13	14	P-40457
.60	API T39	.60 AC T17E3	500	20	13	6	P-40479
.60	API T39	.60 AC T17E3	500	20	13	15	P-40480
.60	Inc T36E2	.60 AC T17E3	500	20	13	6	P-40481
.60	Inc T36E2	.60 AC T17E3	500	20	13	13	P-40482
20mm	HEI M97	20mm AC M3	500	20	13	9	P-40458
20mm	HEI M97	20mm AC M3	500	20	13	6	P-40453
20mm	Inc M96	20mm AC M1A2	500	20	13	9	P-40459
20mm	Inc M96	20mm AC M1A2	500	20	13	14	P-40460
37mm	HE M54	37mm AC M1A2	500	20	13	5	P-40461
37mm	HE M54	37mm AC M1A2	500	20	13	2	P-40462

8. Target: B-25J Engines, Rear Above, Burst Fire

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Ø	Total Hits	APG F.R.
.50	API-T M20	.50 Mann Barrel (36" long)	500	19	13	5	P-40113
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	4	P-40114
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	9	P-40115
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	1	P-40116
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	2	P-40422
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	3	P-40423
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	2	P-40424
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	8	P-40425
20mm	HEI M97	20mm AC M3	500	20	13	11	P-40489
20mm	HEI M97	20mm AC M3	500	20	13	3	P-40490
20mm	Inc M96	20mm AC M3	500	20	13	8	P-40491
20mm	Inc M96	20mm AC M3	500	20	13	8	P-40492
37mm	HE M54	37mm AC M9	500	20	13	2	P-40493
37mm	HE M54	37mm AC M9	500	20	13	5	P-40494

9. Target: P-59 Engine, Jet Units (GE I-16 Turbo-Jet) Front

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	4	5	P-41095
.50	API-T M20	.50 Mann Barrel (36" long)	500	20			P-41094
.50	API T49	.50 Mann Barrel (36" long)	500	20	4	7	P-41233
.50	Inc M23	.50 Mann Barrel (36" long)	500	20	4	9	P-41231
20mm	HEI M97						P-41433
20mm	HEI M97						P-41435
3cm	HE Mk108	3cm AC Mk108 (Ger.)	100	20	4	2	P-41432

10. Target: P-59 Engine (GE I-16 Turbo Jet) Rear

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	3	7	P-40511
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	0	9	P-41092
.50	API T49	.50 Mann Barrel (36" long)	500	20	0	3	P-41235
.50	Inc M23	.50 Mann Barrel (36" long)	500	20	0	1	P-41230
.50	Inc M23	.50 Mann Barrel (36" long)	500	20	0	3	P-41236
20mmm	HEI M97	20mm AC M3	200	20	0	1	P-41432

C. Structures

1. Target: B-25J Fuselage and Wings, Front Below

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	12	210	P-41048
.60	API T39	.60 Mann Barrel (60" long)	500	20	12	113	P-41075
.60	Inc T36E2,	.60 Mann Barrel (60" long)	500	20	12		P-41437
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	21	12	106	P-41082
20mm	HEI M97	20mm AC M3	500	20	13	64	P-41273
20mm	HEI M97	20mm AC M3	500	19	13	47	P-41282
20mm	HEI M97	20mm AC M3	500	20	13	57	P-41088
20mm	Inc M96	20mm AC M3	500	21	12	82	P-41093
20mm	Inc M96	20mm AC M3	500	19	13	60	P-41267
3cm	HE Mk108	3cm Mk108 (Ger.)	200	20	12	24	P-41232

1. Target: B-25J Fuselage and Wings, Front Below (cont'd)

Ammunition Cal.	Type	Gun	Range (yds)	Line of Fire θ deg.	Ø	Total Hits	APG F.R.
3cm	HE Mk108	3cm Mk108 (Ger.)	200	20	13	17	P-41266
3cm	HE Mk108	3cm Mk108 (Ger.)	200	21	13	20	P-41257
3cm	HE Mk108	3cm Mk108 (Ger.)	200	20	13		P-41445
3cm	HE Mk108	3cm Mk108 (Ger.)					P-41452
37mm	HE M54	37mm AN-M9	500	22	12	13	P-41238
75mm	HE M48	75mm T13E1	100	24	13	4	P-41254
75mm	HE M48	75mm T13E1	100	20	13	7	P-41249

2. Target: B-25J Fuselage and Wings, Rear Above

.50	API-T M20	.50 Mann Barrel (36" long)	500	20	15	214	P-40096
.50	API-T M20	.50 Mann Barrel (36" long)	500	20	13	220	P-40488
.60	API T39	.60 Mann Barrel (60" long)	500	20	13	181	P-40495
.60	API T39	.60 Mann Barrel (60" long)	500	20	15	161	P-40112
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	147	P-40500
.60	Inc T36E2	.60 Mann Barrel (60" long)	500	20	13	98	P-40419
20mm	HEI M97	20mm AN-M2	500	20	13	78	P-40427
20mm	HEI M97	20mm AN-M2	500	20	13	97	P-40514
20mm	HEI M97	20mm AN-M2	500	20	13	57	P-41088
20mm	Inc M96	20mm (T31) AC M3	500	20	13	58	P-40431
20mm	Inc M96	20mm (T31) AC M3	500	20	13	112	P-41018
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	26	P-40447
3cm	HE Mk108	3cm AC Mk108 (Ger.)	200	20	13	16	P-41037
37mm	HE M54	37mm AC M9	500	20	13	31	P-40455
37mm	HE M54	37mm AC M9	500	20	13	26	P-41042
75mm	HE M48	75mm AC T13E1	100	20	13	9	P-40466
75mm	HE M48	75mm AC T13E1	100	20	13	7	P-40465
105mm	HE M1	105mm T7	100	20	13	6	P-40478

Appendix B

ILLUSTRATIONS OF ENGINES

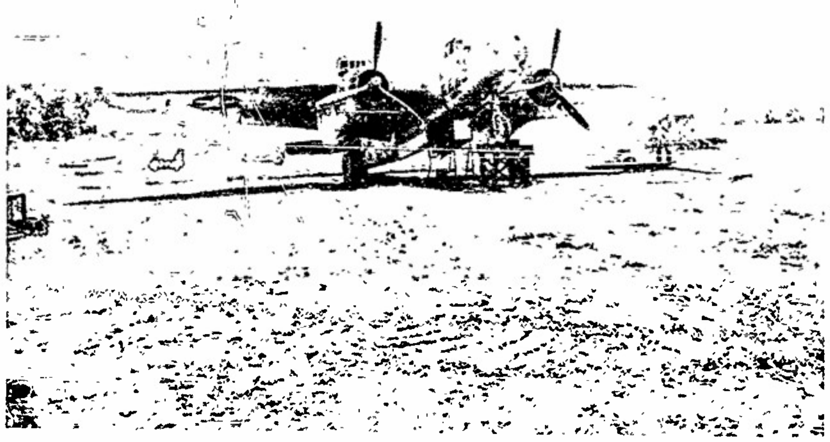


Figure B1 - B-25 Aircraft Set Up For Firing Against Running Engines Front.

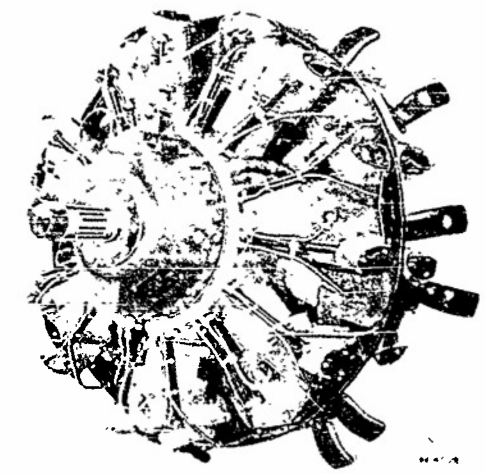


Figure B2a - R-2600-13, -29 Wright Engine

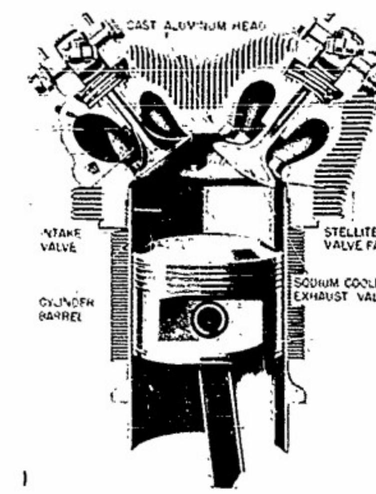


Figure B2b - R-2600 Cylinder Cross Section

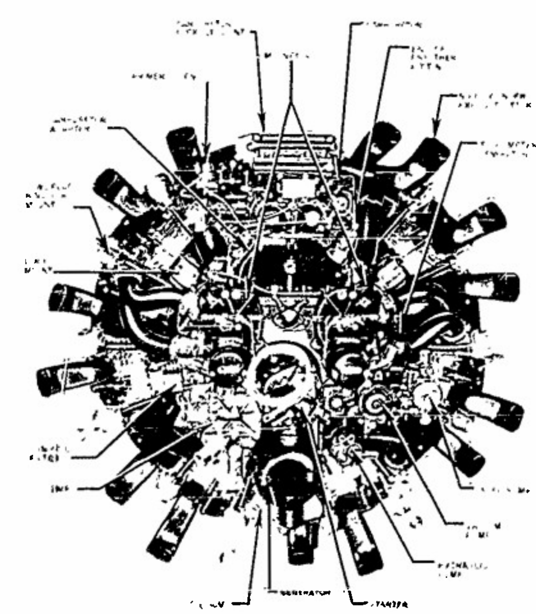
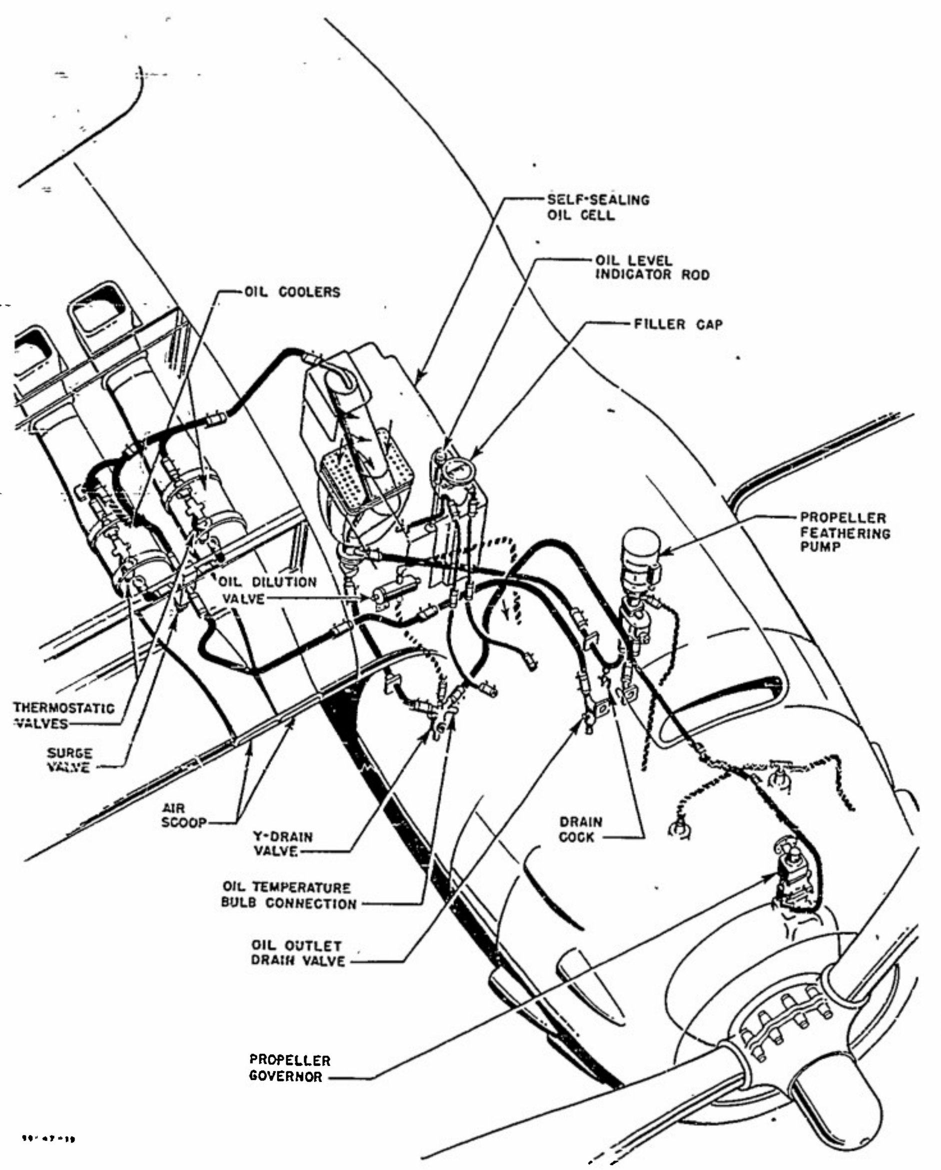


Figure B3 - R-2600 Engine Accessories



B-25 OIL SYSTEM

Figure B4 - B-25 Oil System

Figure B5 - Cal. .50, API-T, M20 Ammunition Against Front of P-38 Running Engine.

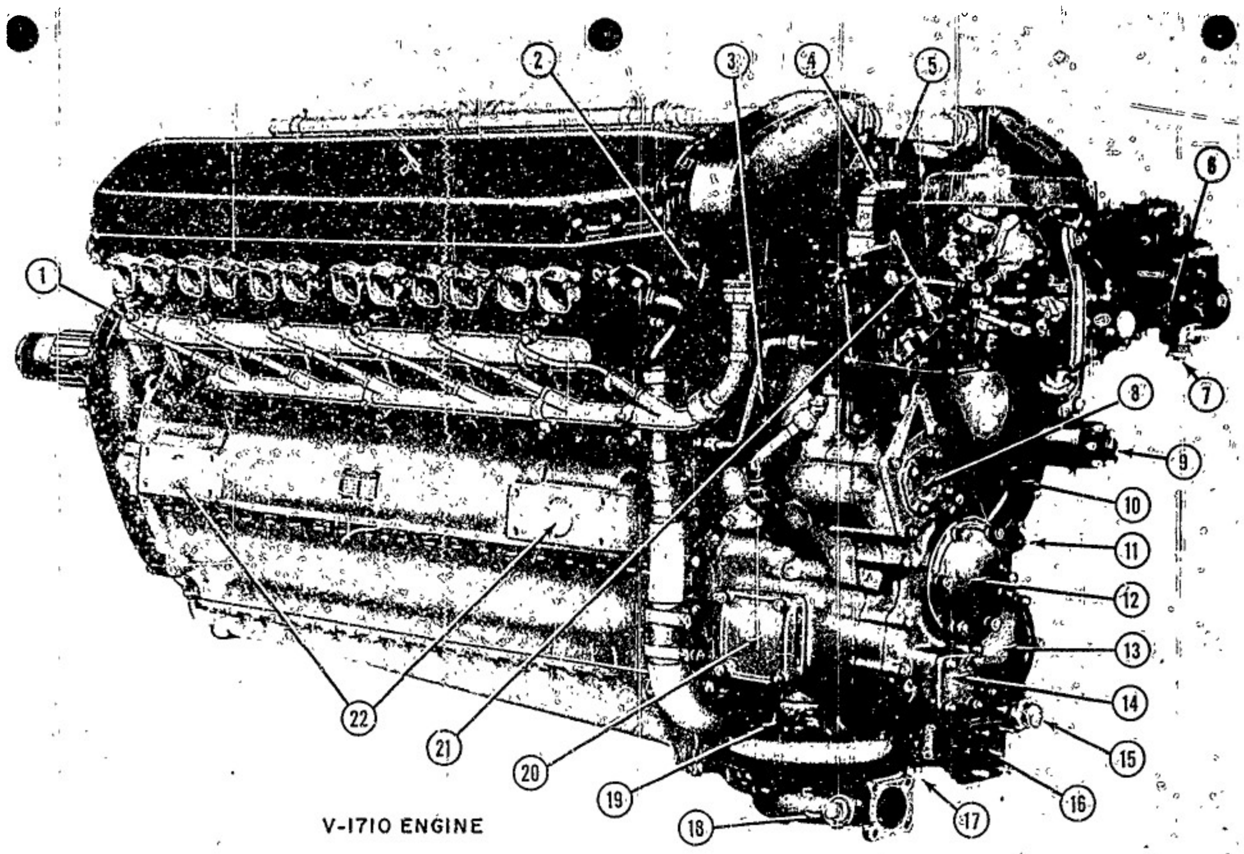


Figure B6 - Location of Accessories and Connections on Engine.

1—Spark Plug Cooling Manifold Inlet
2—Distributor Housing Drains
3—Electric Tach. Drive Flange
4—Rear Breather
5—Magneto
6—Fuel Pressure Gauge Conn.
7—Fuel Inlet
8—Rear Vacuum Pump Flange
9—To Fuel Injector
10—Mixture Thermometer Connection
11—Oil Pressure Connection
12—Generator Flange
13—Starter Flange
14—Fuel Pump Flange
15—Pressure Relief Valve
16—Oil Pump Inlet
17—Oil Pump Outlet
18—Expansion Tank Connection
19—Coolant Pump Seal Drain
20—Side Vacuum Pump Flange
21—Pressure Control Main Lever
22—Engine Mounts

LEFT ENGINE INSTALLATION SHOWN—RIGHT ENGINE INSTALLATION FUNDAMENTALLY THE SAME

(A)-AUTOSYN CONTROLLED TEMPERATURE GAUGE
(B)-COOLANT TEMPERATURE WARNING SIGNALS (LIGHTS)
(C)-EXPANSION TANK FILLER CAP & ACCESS DOOR
(D)-VENT VALVE TO OUTSIDE SHIP (SEE DETAIL)
(E)-VENTS FROM CYLINDER HEADS TO EXPANSION TANK
(F)-VENT LINE FROM RADIATORS TO EXPANSION TANK
(G)-THERMOMETER WELL FOR TEMPERATURE WARNING SIGNAL CONNECTED TO ELECTRICAL JUNCTION BOX
(H)-THERMOMETER WELL FOR TEMPERATURE GAUGE CONNECTED TO AUTOSYN JUNCTION BOX
(I)-AIRBLEED COCK
(J)-AIRSCOOP FOR RADIATORS
(K)-2 RADIATORS (CARTRIDGE CORE TYPE) ATTACHED TO BOOM STRUCTURE BY 4 (EACH) LORD BUSHINGS
(L)-RADIATOR AIR EXIT SHUTTERS HYDRAULICALLY OPERATED FROM CONTROL HANDLE IN COCKPIT
(M)-DRAIN COCKS
(N)-AUTOSYN INSTRUMENT JUNCTION BOX
(O)-COOLANT PUMP SEAL DRAIN
(P)-LOCATION OF THERMOMETER WELL FOR TEMPERATURE GAUGE ON RIGHT ENGINE INSTALLATION ONLY
(Q)-COOLANT EXPANSION LINE

—CAPACITIES—
COOLANT CAPACITY ENTIRE SYSTEM APPROX 25 GALS.
COOLANT CAPACITY OF TANK 18 GALS
EXPANSION SPACE - 2 GALS

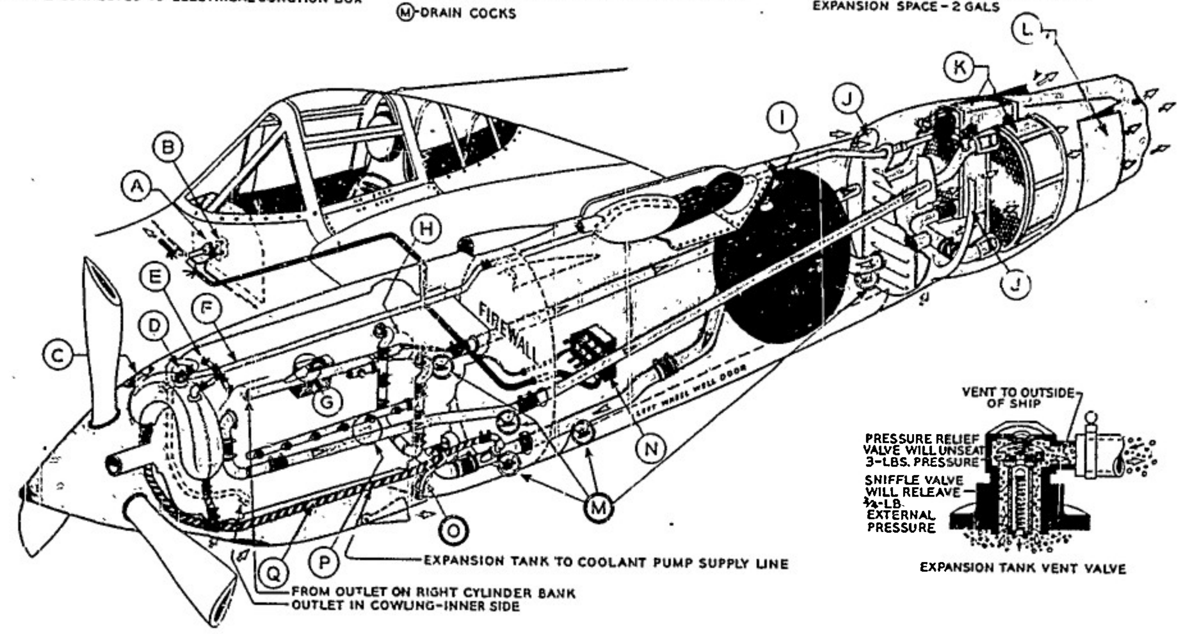
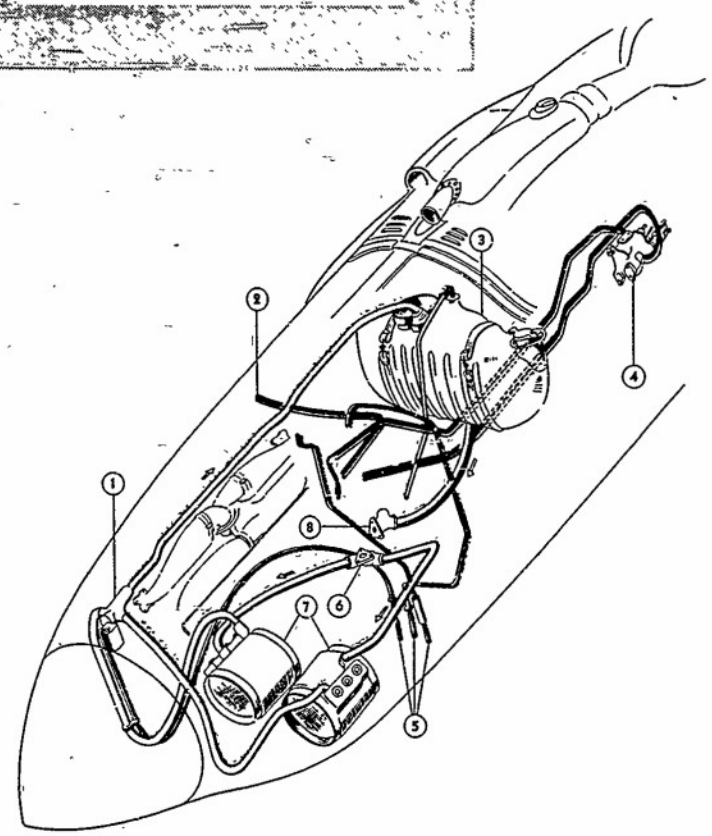


Figure B7 - Typical Coolant System - V-1710 Engine in P-38 Type Airplane.

1. Automatic oil temperature regulator.
2. Line to oil pressure gage.
3. Oil tank (capacity 13 U.S. gal, 11 Imperial gal.).
4. Supercharger regulator. (EARLY AIRPLANES ONLY)
5. Vents to atmosphere.
6. Oil from engine.
7. Oil cooling radiators.
8. Oil to engine.



P-38

Figure B8 - Oil System Diagram

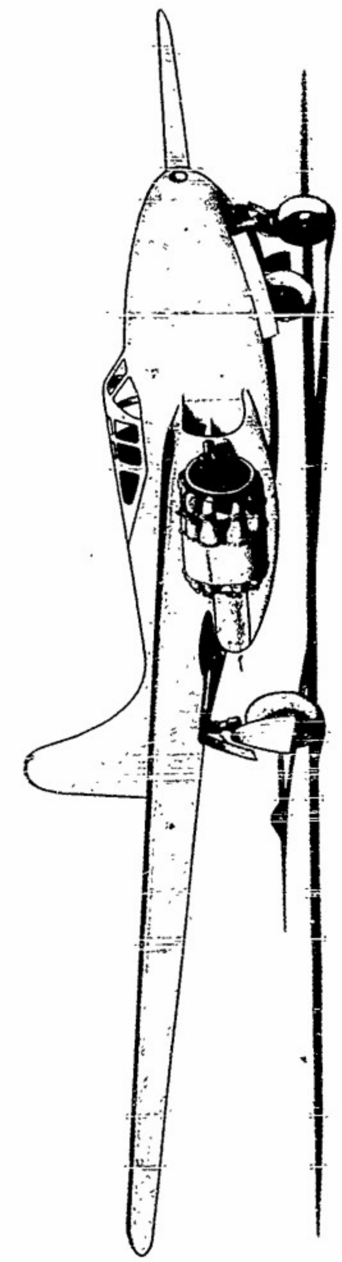
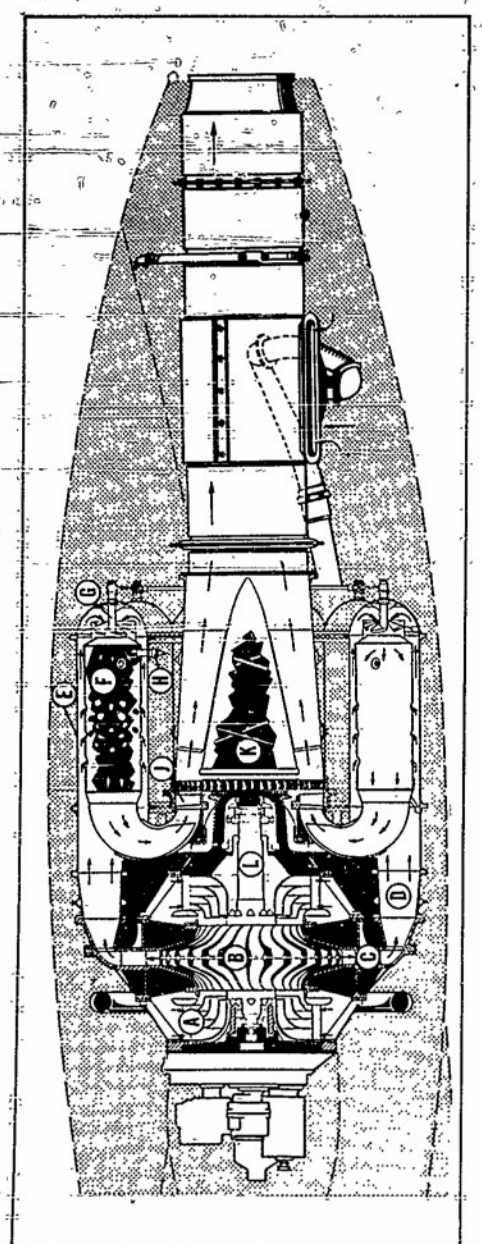


Figure B9 - Diagrammatic Installation of Turbo-Jet Engine for Jet Propulsion I-16 Engine in P-59 Fighter



G.E. I-16 JET UNIT

A - AIR INLET
B - DOUBLE BLADED IMPELLER
C - DIFFUSER CASING
D - TUBE
E - OUTER COMPRESSOR CASING
F - COMBUSTION CHAMBER
G - NOZZLE
H - SPARK PLUG
J - NOZZLE DIAPHRAGM
K - BUCKET WHEEL
L - SHAFT

FIG. B10

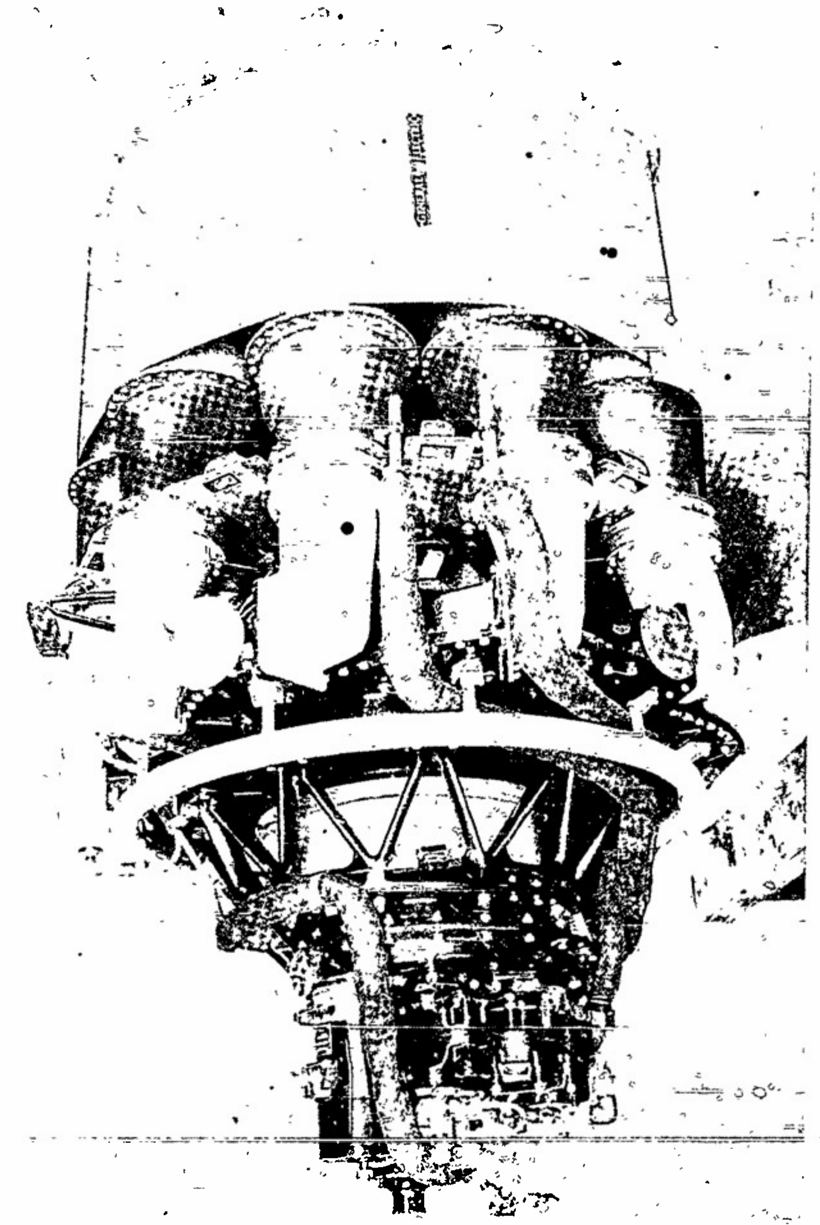


Figure B11 - Three-quarter Front Right View of Power Plant, I-16 Jet Engine.

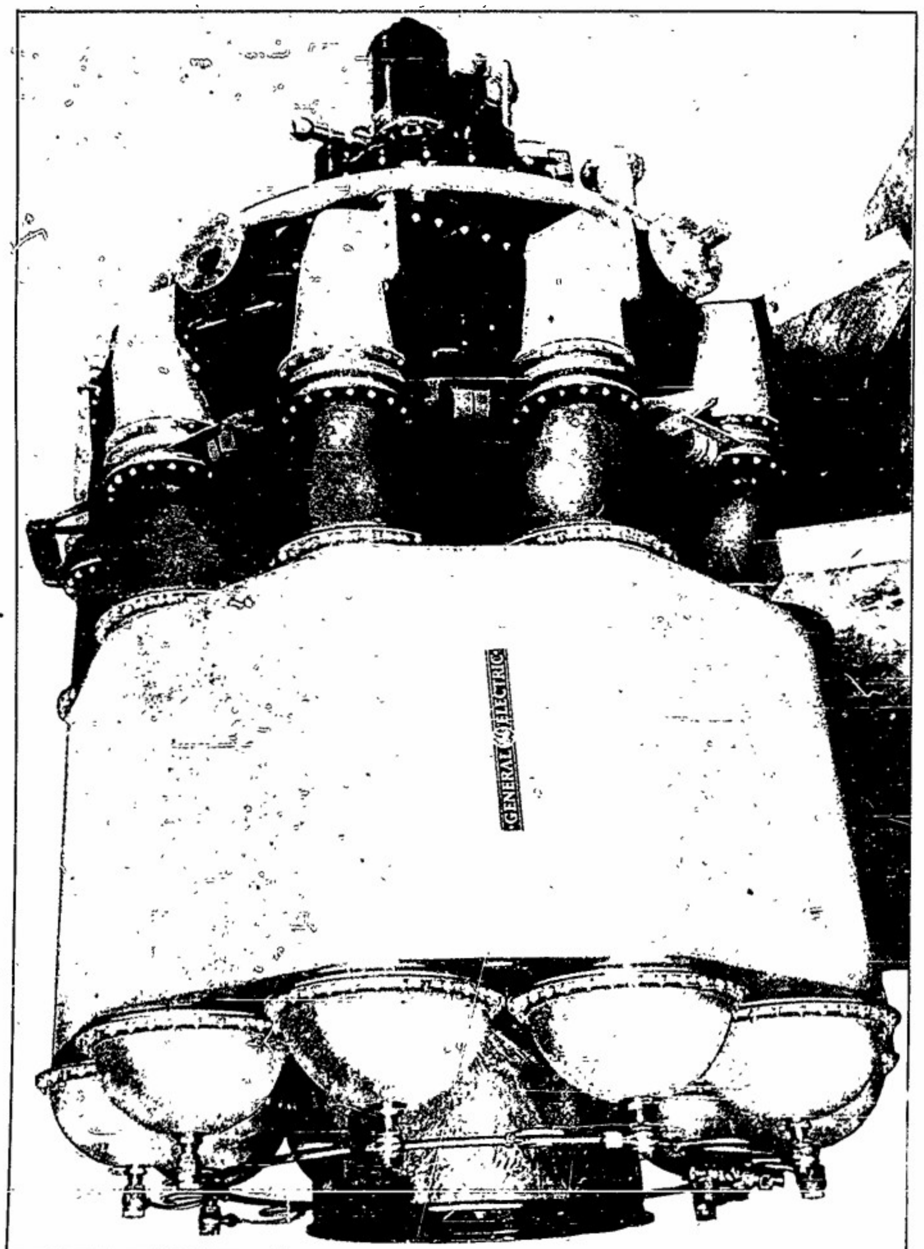


Figure B12 - Three-quarter Rear Left View of Power Plant, I-16 Jet Engine.

Figure B13 - P47 Aircraft With Auxiliary Tank Behind Sandpile To Supply Gas For Running The Motor.

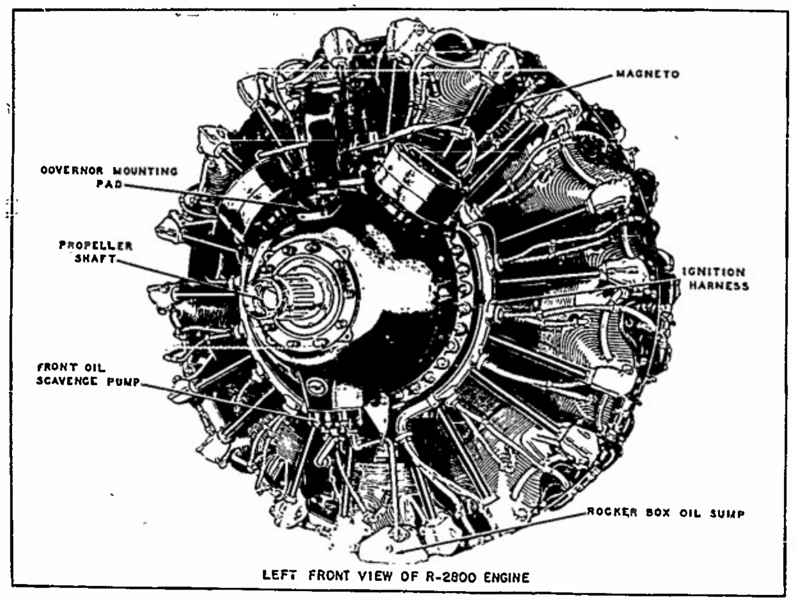


Figure B14 - Left Front View Of R-2800 Engine.

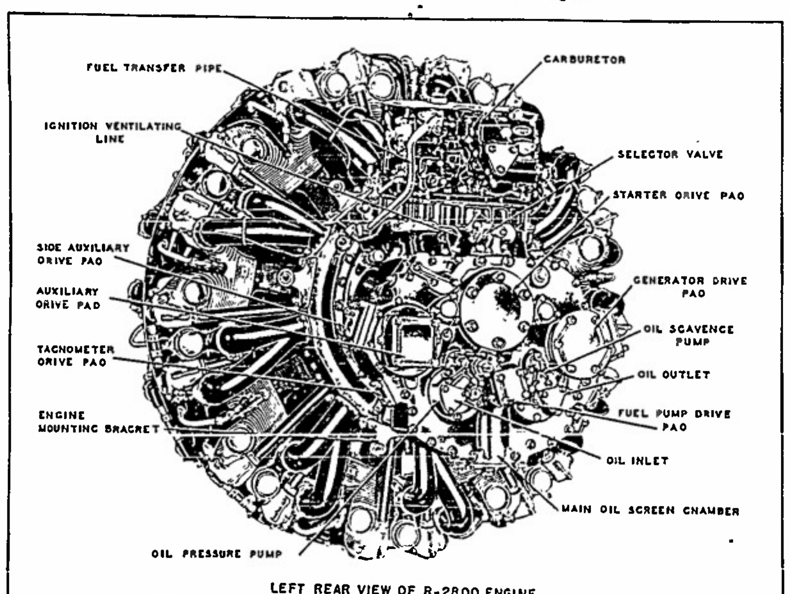


Figure B15 - Left Rear View Of R-2800 Engine.

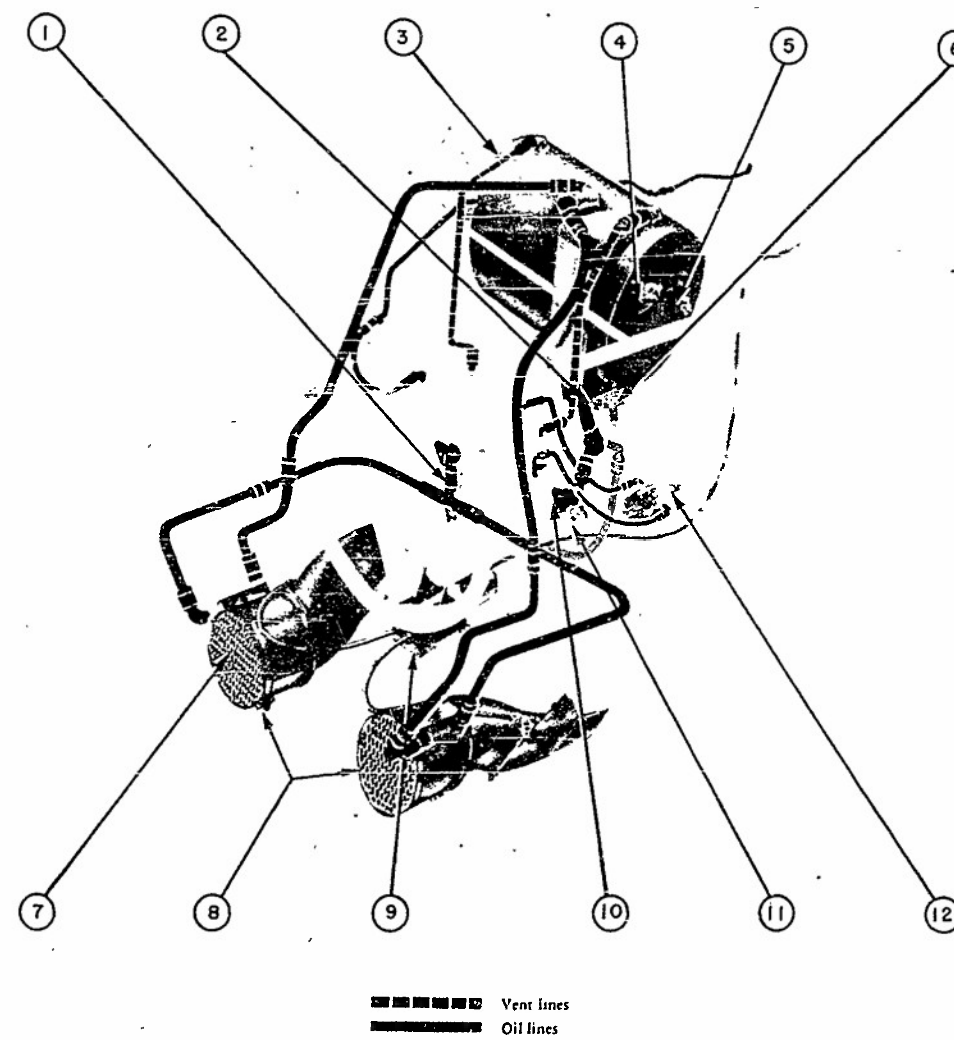


Figure B16 - Oil System, P47D-15-RE to P47D-25-RE.

1. Oil from Engine
2. Oil Tank Sump Drain
3. Oil Tank
4. Oil Tank Filler Neck
5. Normal Load Oil Level Pet Cock
6. Oil Tank Drain
7. Oil Coolers
8. Oil Cooler Drains
9. Oil Cooler Door Operating Mechanism
10. Oil to Engine
11. "Y" Drain
12. Supercharger Regulator

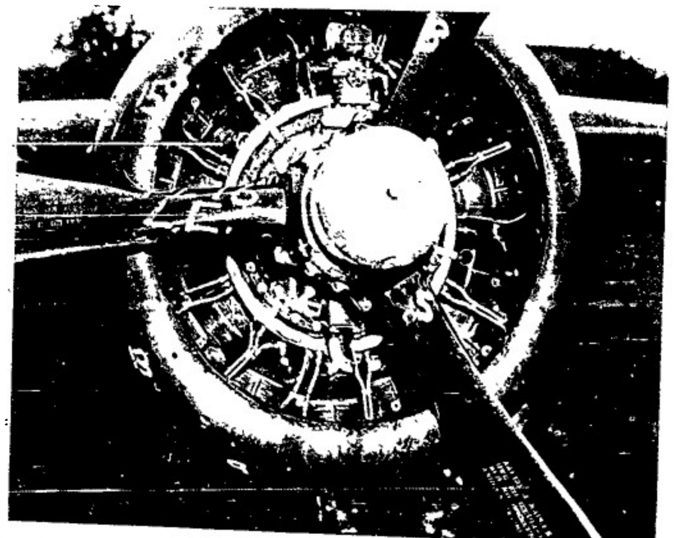


Figure B17 - Cal. .50 API-T, M20 Ammunition Against Front of B25 Running Engine.

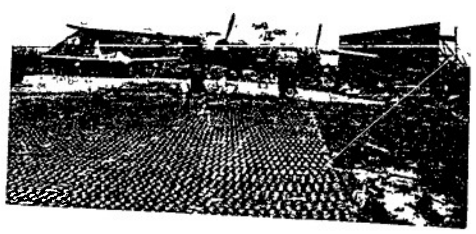


Figure B18 - P59 Aircraft Running Units.

Appendix C

TABLES RELATING TO ENGINE DAMAGE

Ammun. Cal. Type	No. of Hits H	No. of Immed-iate Kills K	No. of "A" Kills A	Prob. of an "A" Kill P_A	Upper Confi-dence Limit UCL(95%) $\bar{P}_A$	Lower Confi-dence Limit LCL(95%) $\underline{P}_A$	No. of "B" Kills B	Prob. of a "B" Kill P_B	Upper Confi-dence Limit UCL(95%) $\bar{P}_B$	Lower Confi-dence Limit LCL(95%) $\underline{P}_B$
C1. Single Shot Engine Damage for P-47 Engine Front & Below $\theta = 20°$, $\phi = 20°$										
Cal. 0.50 API-T M20	63	0	.20	.003	.06	.00	3.69	.059	.15	.02
Cal. 0.60 API - T39	21	1	2.42	.115	.35	.02	3.74	.178	.41	.05
20 MM, HEI M97	16	0	.40	.025	.26	.00	3.72	.233	.41	.05
C2. Single Shot Engine Damage for B-17 Engine Front & Below $\theta = 20°$, $\phi = 7°$										
Cal. 0.50, API-T M20	36	2	2.06	.057	.18	.02	5.54	.154	.30	.07
Cal. 0.60, API- T39	24	1	2.50	.104	.30	.02	3.60	.150	.36	.04
20 MM, HEI M97	19	1	1.32	.070	.31	.00	5.24	.276	.52	.09
C3. Single Shot Engine Damage for P-38 Engine Front & Below $\theta = 20°$, $\phi = 13°$										
Cal. 0.50, API-T M20	22	0	.75	.034	.27	.00	7.50	.341	.58	.15
Cal. 0.60, API- T39	12	0	4.70	.392	.70	.12	8.10	.675	.90	.35
Cal. 0.60 Inc T36 E2	18	0	.75	.042	.25	.00	9.83	.546	.77	.30

Ammun. Cal. Type	No. of Hits H	No. of Immed-iate Kills K	No. of "A" Kills A	Prob. of an "A" Kill P_A	Upper Confi-dence Limit UCL(95%) $\bar{P}_A$	Lower Confi-dence Limit LCL(95%) $\underline{P}_A$	No. of "B" Kills B	Prob. of a "B" Kill P_B	Upper Confi-dence Limit UCL(95%) $\bar{P}_B$	Lower Confi-dence Limit LCL(95%) $\underline{P}_B$
C4. Single Shot Engine Damage for B-25 Engine Front & Below $\theta = 20°$, $\phi = 13°$										
Cal. 0.50 Inc M23	50	0	.00	.000	.08	.00	4.70	.095	.22	.03
Cal. 50 API-T M20	112	0	.10	.001	.04	.00	12.72	.112	.18	.07
Cal. 0.60 API T39	79	1	2.50	.032	.11	.01	24.97	.316	.43	.22
Cal. 0.60 Inc T36E2	73	0	1.00	.014	.10	.01	15.65	.214	.34	.17
20 MM Inc M96	57	0	.80	.014	.07	.01	13.78	.242	.38	.16
20 MM HEI M97	73	0	1.00	.017	.07	.00	13.85	.189	.31	.11
3cm HE Ger M108	20	0	.00	.000	.18	.00	6.45	.323	.57	.13
37 MM HE M54	20	0	3.40	.170	.41	.04	10.45	.522	.75	.29
C5. Single Shot Engine Damage for B-25 Engine Front & Above $\theta = 20°$, $\phi = -13°$										
Cal. 0.50 API-T M20	16	1	1.00	.062	.30	.00	4.40	.264	.55	.08
20 MM, HEI M97	14	0	.94	.067	.33	.00	2.63	.188	.46	.03
20 MM, Inc M96	17	0	1.77	.104	.28	.03	5.70	.335	.59	.13

Ammun. Cal. Type	No. of Hits H	No. of immed-iate Kills K	No. of "A" Kills A	Prob. of an "A" Kill P_A	Upper Confi-dence Limit UCL(95%) $\bar{P}_A$	Lower Confi-dence Limit LCL(95%) $\underline{P}_A$	No. of "B" Kills B	Prob. of a "B" Kill P_B	Upper Confi-dence Limit UCL(95%) $\bar{P}_B$	Lower Confi-dence Limit LCL(95%) $\underline{P}_B$
C6. Single Shot Engine Damage for B-25 Engine Rear & Above $\theta = 20°$, $\phi = 13°$										
Cal. 0.50 API-T M20	155	0	2.05	.013	.04	.00	9.28	.060	.12	.03
Cal. 0.60 API T39	20	0	1.05	.050	.26	.00	2.86	.143	.37	.03
Cal. 0.60 Inc T36E2	42	0	1.16	.028	.14	.00	4.30	.102	.24	.06
20 MM, HEI M97	46	0	1.09	.024	.13	.00	7.60	.165	.31	.07
20 MM, Inc M96	34	0	2.00	.059	.11	.00	7.25	.213	.38	.18
3cm, Germ HE M108	5	1	2.05	.410	.89	.06	2.15	.430	.87	.06
37 MM, HE, M54	21	0	.00	.000	.17	.00	2.15	.103	.29	.02
C7. Single Shot Engine Damage B-25 Engine Rear & Below $\theta = 20°$, $\phi = -13°$										
Cal. 0.50, API-T M20	35	0	4.00	.114	.27	.06	8.30	.237	.42	.11
Cal. 0.60 API T39	12	0	1.40	.117	.45	.01	3.11	.259	.59	.05
Cal. 0.60 Inc T36E2	8	0	.00	.000	.37	.00	2.25	.282	.68	.04
20 MM HEI M97	12	0	.50	.042	.36	.00	5.30	.442	.74	.17
20 MM Inc M96	25	2	2.65	.160	.47	.04	5.25	.210	.42	.07
3cm, Ger HE M108	3	1	1.00	.333	.90	.01	2.05	.683	.99	.10
37 MM, HE M54	8	0	2.10	.250	.66	.03	4.30	.504	.86	.18

Ammun. Cal. Type	No. of Hits H	No. of immed-iate Kills K	No. of "A" Kills A	Prob. of an "A" Kill P_A	Upper Confi-dence Limit UCL(95%) $\bar{P}_A$	Lower Confi-dence Limit LCL(95%) $\underline{P}_A$	No. of "B" Kills B	Prob. of an "B" Kill P_B	Upper Confi-dence Limit UCL(95%) $\bar{P}_B$	Lower Confi-dence Limit LCL(95%) $\underline{P}_B$
C8. Single Shot Engine Damage P-38 Engine Rear & Above $\theta = 20°$, $\phi = 13°$										
Cal. 0.50 API-T M20	13	0	.50	.038	.31	.00	4.60	.354	.67	.12
Cal. 0.60 API T39	14	0	3.33	.238	.54	.06	4.10	.293	.60	.09
Cal. 0.60 Inc T36E2	13	0	5.18	.398	.69	.15	7.60	.585	.85	.28
C9. Combined Results B-17, P-47, B-25 Engines Front and Below										
Cal. 0.50 INC M23	50	0	.00	.000	.08	.00	4.70	.095	.22	.03
Cal. 0.50 API-T M20	211	2	2.36	.011	.03	.00	21.95	.104	.15	.06
Cal. 0.60 API T39	124	3	7.42	.060	.11	.03	32.31	.261	.35	.15
Cal. 0.60 Inc T36E2	73	0	1.00	.014	.10	.01	15.65	.214	.34	.17
20 MM Inc M96	57	0	.80	.014	.07	.01	13.78	.242	.38	.16
20 MM HEI M97	108	1	2.72	.025	.05	.00	22.81	.211	.30	.13
3cm HE M108	20	0	.00	.000	.17	.00	6.45	.323	.57	.13
37 MM HE M54	20	0	3.40	.170	.41	.04	10.45	.522	.75	.29

TABLE C 10

Firings Against P59 Jet Units

Ammunition	Line of Fire	Number Hits	Immediate Kills	Sum of Damage A	Sum of Damage B	Probability of a Kill P_A	Probability of a Kill P_B
Cal. 0.50 API-T, M20	Front	5	3	3.00	3.00	.600	.600
	Rear	8	4	4.00	5.00	.500	.625
Cal. 0.50 API, T49	Front	4	0	.00	2.00	.000	.162
	Rear	2	0	.00	1.00	.000	.500
Cal. 0.50 INC, M23	Front	5	3	3.00	4.00	.600	.630
	Rear	3	1	2.00	2.00	.667	.667
20mm, HEI, M97	Front	2	2	2.00	2.00	1.000	1.000
	Rear	2	1	2.00	2.00	1.000	1.000
3cm German, M108 Static	Front	2	2	2.00	2.00	1.000	1.000
	Rear	0	-	-	-	-	-

TABLE C 11

Single Shot Damage to I-16 Jet Engine

Ammunition	Line of Fire	Assessment A	Assessment B	Assessment C	Assessment E	Description of Damage
Cal. .50 API-T, M20						
Rd. 1	Front	K	100	-	-	Low Pressure fuel line cut 50%.
Rd. 2	F	K	100	-	-	Main fuel filter shattered, large fire.
Rd. 3	F	0	0	0	0	Gear case housing, 1-1/2" hole.
Rd. 4	F	0	0	0	0	Gear case air vent, 1/4" hole.
Rd. 5	F	K	100	-	-	#8 and #5 burner air adapter elbow cut open, small fire.
Rd. 1	Rear	0	62	0	0	#7 burner, #6 burner elbow blow out.
Rd. 2	R	K	100	-	-	Core and fragments cut fuel manifold pigtail and #2 burner, also explosion.
Rd. 3	R	K	100	-	-	Core severed main fuel high pressure line.
Rd. 4	R	0	0	0	0	Hole in tailpipe and severed thermocouple wire.
Rd. 5	R	0	0	0	0	Hole in tailpipe, cumulative fire.
Rd. 6	R	K	100	-	-	Severed pigtail and hole in #8 burner.
Rd. 7	R	0	0	0	0	1/2" hole #3 burner.
Rd. 8	R	K	100	-	-	2-1/2" x 1-1/2" hole #6 burner and severed pigtail, medium fire.
Cal. .50 API, T49						
Rd. 1	Front	0	0	0	0	Electrical leads to starter out by fragments.
Rd. 2	F	0	0	0	0	Gear case breather line cut 75% by fragments.
Rd. 3	F	0	[illegible]	[illegible]	0	Core made 1-1/2" x 1" hole in compressor casing cutting vane.
Rd. 4	F	0	15	0	0	Pierced oil pressure line to bearing.
Rd. 1	Rear	0	0	0	0	1" hole in #4 burner.
Rd. 2	R	0	50	0	0	Turbine buckets bent.
Cal. .50 Inc., M23						
Rd. 1	Front	0	0	0	0	Fragments cut 1/2 dia. hole in compressor casing.
Rd. 2	F	K	100	-	-	Fragments severed high pressure fuel line.
Rd. 3	F	0	15	0	0	Fragments made 1" x 1/8" hole in main oil line.
Rd. 4	F	K	100	-	-	Fragments severed high pressure fuel line large fire.
Rd. 5	F	K	100	-	-	Fragments severed 25% low pressure fuel line.
Rd. 1	Rear	0	0	0	0	Small hole in #1 and #2 burners.
Rd. 2	R	100	100	-	-	Hole 4" x 2" in #6 burner and 9" x 10" hole in #7 burner, Fire resulted in 2 min.
Rd. 3	R	K	100	-	-	Severed pigtail and 4" x 3" hole #6 burner and 3" hole #7 burner, large fire.
20mm HEI, M97						
Rd. 1	Front	K	100	-	-	Fragments cut open high and low Pressure fuel line.
Rd. 2	F	K	100	-	-	Fragments 50% severed fuel line to fuel booster, medium fire.
Rd. 1	Rear	100	100	-	-	Turbine buckets 90% dented and one broken, fire.
Rd. 2	R	K	100	-	-	#3 and #4 burners torn open, medium fire.
3cm. HE MK108*						
Rd. 1	Front	K	100	-	-	Main fuel line pierced.
Rd. 2	F	K	100	-	-	#7, #8, #9 burners torn open.

* Engine not running.

TABLE C12

ENGINE COMPONENT DAMAGE

B-25 Front Below, = 20°, = 15°

Caliber / Components	Cal .50 API-T, M20 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .40 API T36 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .60 Inc. T36E2 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Components																								
1 Propeller	9	.08	0	100	0	0	0	33	2	.03	0	100	0	0	0	50	13	.16	0	100	0	0	3	40
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
3 Prop. Governor	3	.02	0	0	0	0	0	0	1	.01	0	00	0	00	0	00	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gear, Cams, etc.	4	.05	0	15	0	5	0	10	2	.03	0	15	0	10	0	15	3	.04	0	0	0	0	0	0
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	2	.02	0	100	0	0	0	50	2	.03	0	5	0	0	0	3	4	.05	0	64	0	0	0	22
8 Ignition Leads	7	.06	0	100	0	0	0	5	4	.05	0	3	0	0	0	3	4	.05	0	0	0	0	0	1
9 Spark Plugs	0	0	-	-	-	-	-	-	1	.01	0	0	0	0	0	0	1	.01	0	0	0	0	0	0
10 Push Rods	3	.03	0	100	0	0	0	5	3	.04	0	3	0	0	0	3	4	.05	0	5	0	0	0	3
11 Push Rod Covers	1	.01	0	0	0	0	0	0	2	.03	0	5	0	0	0	3	1	.01	0	0	0	0	0	0
12 Rocker Boxes	7	.06	0	100	0	5	0	4	3	.04	0	5	0	5	0	3	2	.03	0	5	0	0	0	3
13 Rocker Arms	0	0	-	-	-	-	-	-	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-
14 Cylinder Heads	3	.03	0	5	0	0	0	3	6	.08	0	5	0	0	0	0	3	.04	0	5	0	5	0	5
15 Cylinder Barrels	3	.03	0	3	0	0	0	4	4	.05	0	100	0	5	0	00	4	.05	0	5	0	5	0	5
16 Oil Sump	0	0	-	-	-	-	-	-	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-
17 Oil Lines	0	0	-	-	-	-	-	-	2	.03	0	100	0	35	0	77	2	.03	0	100	0	100	0	100
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	3	.04	0	100	0	100	0	100
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	1	.01	0	37	0	37	0	57	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-	1	.01	0	0	0	0	0	0
22 Intake Tubes	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
23 Carburetor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
24 Accessories-Starter Generator, Filter, Oil Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.01	0	100	0	100	0	100
25 Fuel Lines	1	.01	0	0	0	0	0	0	3	.03	100	100	0	100	00	100	2	.03	100	100	0	100	50	100
26 Control Linkages	1	.01	0	0	0	0	0	0	1	.01	50	100	50	100	50	100	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	4	.04	0	100	0	15	0	72	4	.05	0	100	0	25	0	62	1	.01	0	100	0	100	0	100
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
Functional Component																								
A Lub. System	15	.13	0	100	0	0	0	42	13	.19	0	100	0	0	0	42	6	.12	0	100	0	100	0	66
B Mech. Power Losses	27	.24	0	100	0	5	0	6	15	.19	0	37	0	0	0	10	16	.22	0	0	0	0	0	4
C Exhaust System	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-	1	.01	0	0	0	0	0	0
D Induction System	3	.03	0	5	0	0	0	2	2	.03	100	100	0	100	50	100	3	.04	100	100	0	0	33	66
E Ignition & Magnetos	5	.05	0	100	0	0	0	2	2	.00	100	100	0	100	16	.16	8	.11	0	25	0	0	0	16
F Control Damage affecting Engine Performance	0	.07	0	0	0	0	0	0	1	.01	50	100	50	100	00	100	11	.14	0	0	0	0	0	0

Caliber / Components	20mm HEI M97 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm Inc. M96 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	3cm. MK108 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	37mm No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Components																																
1 Propeller	4	.05	0	100	0	0	0	25	5	.07	0	0	0	0	0	0	0	0	-	-	-	-	-	-	1	.05	100	100	100	100	100	100
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	1	.02	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
3 Prop. Governor	1	.01	0	0	0	0	0	0	1	.02	0	100	0	100	0	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gear, Cams, etc.	1	.01	0	5	0	5	0	5	1	.02	10	23	10	23	10	23	0	0	-	-	-	-	-	-	1	.05	0	10	0	10	0	10
5 Scavenging Pump	1	.01	0	5	0	5	0	5	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	1	.01	0	100	0	100	0	100	1	.02	11	10	15	10	15	10	0	0	-	-	-	-	-	-	1	.05	0	10	0	10	0	0
8 Ignition Leads	10	.14	0	15	0	0	0	3	4	.07	0	5	0	0	0	3	1	.05	0	0	0	0	0	0	4	.20	0	15	0	5	0	5
9 Spark Plugs	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
10 Push Rods	4	.05	0	5	0	0	0	4	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	0	0	0	0	0	0
11 Push Rod Covers	2	.03	0	5	0	0	0	3	1	.02	0	0	0	0	0	0	0	0	-	-	-	-	-	-	3	.15	0	0	0	0	0	0
12 Rocker Boxes	2	.03	0	10	0	0	0	7	1	.02	0	15	0	15	0	15	0	0	-	-	-	-	-	-	5	.25	0	10	0	0	0	2
13 Rocker Arms	1	.01	100	100	100	100	100	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	1	.01	0	0	0	0	0	0	4	.07	0	5	0	5	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
15 Cylinder Barrels	0	0	-	-	-	-	-	-	2	.04	0	5	0	5	0	3	0	0	-	-	-	-	-	-	1	.05	0	10	0	10	0	10
16 Oil Sump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	0	100	0	100	0	100
17 Oil Lines	0	0	-	-	-	-	-	-	2	.04	0	100	0	0	0	50	0	0	-	-	-	-	-	-	4	.20	0	100	0	0	0	30
18 Oil Coolers	1	.01	0	100	0	100	0	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	0	0	-	-	-	-	-	-	1	.02	0	10	0	0	0	0	0	0	-	-	-	-	-	-	2	.10	0	0	0	0	0	0
22 Intake Tubes	1	.01	0	5	0	5	0	5	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	2	.10	0	0	0	0	0	0
23 Carburetor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
24 Accessories-Starter Generator, Filter, Oil Pump	0	0	-	-	-	-	-	-	1	.02	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
25 Fuel Lines	1	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	3	.15	100	100	0	0	33	33
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	100	100	100	100	100	100
27 Prop. Dome or Pitch Controlling Motor	2	.00	0	100	0	100	0	100	0	.14	0	100	0	0	0	67	3	0	0	100	0	[illegible]	0	33	0	0	-	-	-	-	-	-
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	0	100	0	100	0	100
Functional Component																																
A Lub. System	8	.11	0	100	0	0	0	40	16	.28	0	100	0	0	0	29	4	.20	0	100	0	[illegible]	0	31	13	.65	0	100	0	0	0	36
B Mech. Power Losses	7	.10	100	100	0	0	14	16	10	.18	10	25	0	5	1	[illegible]	[illegible]	.05	0	0	0	[illegible]	0	0	5	.25	100	100	0	0	20	22
C Exhaust System	0	0	-	-	-	-	-	-	1	.02	0	0	0	0	0	0	1	.05	0	10	0	[illegible]	0	10	2	.10	0	0	0	0	0	0
D Induction System	3	.04	0	100	0	0	0	60	0	0	-	-	-	-	-	-	2	.10	0	10	0	[illegible]	0	5	8	.40	100	100	0	0	15	14
E Ignition & Magnetos	6	.12	0	15	0	0	0	4	6	.10	15	10	0	0	5	8	4	.20	0	100	0	[illegible]	0	29	2	.10	0	5	0	0	0	3
F Control Damage affecting Engine Performance	4	.05	0	0	0	0	0	0	[illegible]	.12	0	0	0	0	0	0	0	0	-	-	-	-	-	-	1	.05	100	100	100	100	100	100

TABLE C13

ENGINE COMPONENT DAMAGE

B-25 Rear, Below = 20°, = 13°

Caliber / Components	Cal .50 API-T, M20 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .40 API T36 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .60 Inc. T36E2 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Component																								
1 Propeller	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
3 Prop. Governor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gear, Cams, etc.	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
8 Ignition Leads	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
9 Spark Plugs	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
10 Push Rods	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
11 Push Rod Covers	3	.02	0	15	0	10	0	5	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
12 Rocker Boxes	1	.03	0	5	0	5	0	5	1	.08	0	5	0	5	0	5	0	0	-	-	-	-	-	-
13 Rocker Arms	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	2	0	2	0	2
14 Cylinder Heads	0	0	-	-	-	-	-	-	1	.00	0	7	0	7	0	7	0	0	-	-	-	-	-	-
15 Cylinder Barrels	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
16 Oil Sump	1	.05	0	100	0	100	0	100	2	.17	0	100	0	100	0	100	0	0	-	-	-	-	-	-
17 Oil Lines	1	.05	0	100	0	100	0	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	2	.25	0	100	0	100	0	100
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	1	.03	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
22 Intake Tubes	4	.11	0	0	[illegible]	2	0	2	5	.42	0	100	0	[illegible]	0	33	3	.38	0	13	0	3	0	7
23 Carburetor	0	0	-	-	-	-	-	-	1	.08	25	50	25	50	25	50	0	0	-	-	-	-	-	-
24 Accessories-Starter Generator, Filter, Oil Pump	2	.06	0	100	0	0	0	50	1	.00	[illegible]	0	0	0	0	0	1	.13	0	0	0	0	0	0
25 Fuel Lines	4	.11	100	100	100	100	100	100	2	.17	100	100	[illegible]	60	54	65	0	0	-	-	-	-	-	-
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
Functional Component																								
A Lub. System	10	.21	0	100	0	50	0	40	3	.25	[illegible]	100	0	90	2	93	2	.25	0	100	0	100	0	100
B Mech. Power Losses	0	0	-	-	-	-	-	-	1	.08	0	7	0	7	0	7	1	.13	0	2	0	2	0	2
C Exhaust System	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
D Induction System	10	.29	100	100	0	0	00	31	4	.20	100	100	[illegible]	50	17	57	3	.38	0	15	0	5	0	0
E Ignition & Magnetos	0	0	-	-	-	-	-	-	1	.00	0	0	0	0	0	0	3	.38	0	0	0	0	0	0
F Control Damage affecting Engine Performance	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0

Caliber / Components	20mm HEI M97 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm Inc. M96 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	3 cm. MK108 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	37mm No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Component																																
1 Propeller	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
3 Prop. Governor	0	0	-	-	-	-	-	-	1	.04	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gear, Cams, etc.	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
8 Ignition Leads	1	.08	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
9 Spark Plugs	0	0	-	-	-	-	-	-	2	.08	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
10 Push Rods	1	.08	0	0	0	0	0	0	2	.08	0	5	0	5	0	5	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
11 Push Rod Covers	0	0	-	-	-	-	-	-	1	.04	0	0	0	0	5	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
12 Rocker Boxes	0	0	-	-	-	-	-	-	3	.12	0	10	0	5	0	[illegible]	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
13 Rocker Arms	0	0	-	-	-	-	-	-	1	.04	0	5	0	5	0	[illegible]	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	0	0	-	-	-	-	-	-	1	.04	0	5	0	[illegible]	[illegible]	5	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
15 Cylinder Barrels	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
16 Oil Sump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
17 Oil Lines	1	.08	0	100	0	100	0	100	0	0	-	-	-	-	-	-	1	.33	0	100	0	100	0	100	1	.13	0	100	0	100	0	100
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	0	0	-	-	-	-	-	-	2	.08	0	0	0	0	0	0	2	.67	0	0	0	0	0	0	1	.13	0	0	0	0	0	0
22 Intake Tubes	3	.25	0	10	[illegible]	[illegible]	[illegible]	3	3	.12	0	5	0	5	0	[illegible]	1	.33	[illegible]	3	0	3	0	5	1	.13	0	0	0	0	0	0
23 Carburetor	0	0	-	-	-	-	-	-	1	.04	100	100	100	100	100	100	0	0	-	-	-	-	-	-	2	.25	0	0	0	0	0	0
24 Accessories-Starter Generator, Filter, Oil Pump	1	.08	0	0	0	0	0	0	[illegible]	.24	0	0	0	0	0	0	1	.33	0	0	0	0	0	0	1	.13	0	0	0	0	0	0
25 Fuel Lines	2	.17	0	0	0	0	0	0	4	.16	100	100	5	100	42	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
28 Oil Tanks	2	.17	0	100	0	100	0	100	1	.04	0	100	0	100	0	100	0	0	-	-	-	-	-	-	1	.13	0	100	0	100	0	100
Functional Component																																
A Lub. System	2	.17	0	100	0	100	0	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	4	.50	0	100	0	100	0	100
B Mech. Power Losses	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
C Exhaust System	0	0	-	-	-	-	-	-	1	.04	0	0	0	0	0	0	0	0	-	-	-	-	-	-	1	.13	0	0	0	0	0	0
D Induction System	1	.08	0	0	0	0	0	0	0	0	-	-	-	-	-	-	1	[illegible]	0	[illegible]	0	5	0	5	3	.38	100	100	0	0	[illegible]	33
E Ignition & Magnetos	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	3	.38	10	33	0	0	[illegible]	10
F Control Damage affecting Engine Performance	0	0	-	-	-	-	-	-	1	.04	0	0	0	0	0	0	0	0	-	-	-	-	-	-	2	.25	0	0	0	0	0	0

C14

ENGINE COMPONENT DAMAGE
B-25 Rear & Above, = 20°, = 13°

Caliber / Components	Cal .50 API-T, M20 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .60 API T39 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Components																
1 Propeller	2	.01	0	5	0	0	0	0	5	.25	0	0	0	0	0	0
2 Prop. Junction Box and Cable	2	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-
3 Prop. Governor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gears, Cams, etc.	1	.004	0	95	0	95	0	95	0	0	-	-	-	-	-	-
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
8 Ignition Leads	1	.006	0	0	0	0	0	0	0	0	-	-	-	-	-	-
9 Spark Plugs	0	0	-	-	-	-	-	-		0	-	-	-	-	-	-
10 Push Rods	1	.004	0	5	0	5	0	5	0	0	-	-	-	-	-	-
11 Push Rod Covers	2	.01	0	2	0	0	0	1	2	.10	0	0	0	0	0	0
12 Rocker Boxes	2	.01	0	30	0	1	3	24	1	.05	0	5	0	5	0	5
13 Rocker Arms	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	2	.01	0	3	0	3	0	3	0	0	-	-	-	-	-	-
15 Cylinder Barrels	1	.004	0	5	0	5	0	5	0	0	-	-	-	-	-	-
16 Oil Sump	0	0	-	-	-	-	-	-	1	.05	0	100	0	100	0	100
17 Oil Lines	4	.03	0	100	0	100	0	100	2	.10	0	100	0	5	0	52
18 Oil Coolers	3	.02	25	100	0	100	8	100	2	.10	0	15	0	15	0	19
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	2	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-
22 Intake Tubes	2	.01	100	100	5	5	32	32	3	.15	0	1	0	1	0	1
23 Carburetor	5	.03	100	100	0	0	40	40	2	.10	100	100	100	100	100	100
24 Accessories-Starter Generator, Filter, Oil Pump	2	.01	0	0	0	0	0	0	0	0	-	-	-	-	-	-
25 Fuel Lines	4	.03	0	5	0	0	0	1	4	.20	0	0	0	0	0	0
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
28 Oil Tanks	5	.03	0	100	0	30	0	30	4	.20	0	10	0	0	0	5
Functional Components																
A Lub. System	16	.10	0	100	0	0	0	16	14	.70	0	100	0	0	0	17
B Mech. Power Losses	4	.03	0	0	0	0	0	0	1	.05	5	50	5	50	5	50
C Exhaust System	2	.01	0	0	0	0	0	0	1	.05	0	5	0	5	0	5
D Induction System	11	.07	100	100	0	0	34	37	5	.25	0	1	0	0	0	0
E Ignition & Magnetos	1	.004	0	0	0	0	0	0	0	0	-	-	-	-	-	-
F Control Damage Affecting Engine Performance	2	.01	0	0	0	0	0	0	4	.20	100	100	0	0	50	50

Caliber / Components	Cal .60 Inc. T36E2 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm HEI M97 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
1 Propeller	3	.07	0	0	0	0	0	0	4	.09	0	0	0	0	0	0
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
3 Prop. Governor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gears, Cams, etc.	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
8 Ignition Leads	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
9 Spark Plugs	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
10 Push Rods	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
11 Push Rod Covers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
12 Rocker Boxes	0	0	-	-	-	-	-	-	1	.02	0	0	0	0	0	0
13 Rocker Arms	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
15 Cylinder Barrels	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
16 Oil Sump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
17 Oil Lines	4	.10	15	100	0	100	5	100	9	.20	0	100	0	0	0	77
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
22 Intake Tubes	4	.10	0	10	0	5	0	6	2	.04	0	5	0	5	0	5
23 Carburetor	0	0	-	-	-	-	-	-	1	.02	0	0	0	0	0	0
24 Accessories-Starter Generator, Filter, Oil Pump	2	.05	0	0	0	0	0	0	1	.02	0	0	0	0	0	0
25 Fuel Lines	1	.02	100	100	100	100	100	100	3	.07	100	100	9	100	69	100
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
Functional Components																
A Lub. System	5	.12	15	100	0	100	4	82	10	.22	0	100	0	0	0	50
B Mech. Power Losses	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
C Exhaust System	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
D Induction System	7	.17	100	100	0	5	50	43	5	.11	100	100	9	100	21	42
E Ignition & Magnetos	1	.02	0	0	0	0	0	0	1	.02	0	0	0	0	0	0
F Control Damage Affecting Engine Performance	3	.07	0	10	0	0	0	5	4	.09	0	0	0	0	0	0

Caliber / Components	20mm Inc. M96 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	3cm. HE108 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	37mm No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
1 Propeller	1	.03	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
3 Prop. Governor	0	0	-	-	-	-	-	-	1	.20	0	0	0	0	0	0	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gears, Cams, etc.	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	2	.10	0	0	0	2	0	3
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
8 Ignition Leads	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	2	.10	0	2	0	2	0	3
9 Spark Plugs	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
10 Push Rods	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	0	0	0	0	0	0
11 Push Rod Covers	0	0	-	-	-	-	-	-	1	.20	0	0	0	0	0	0	0	0	-	-	-	-	-	-
12 Rocker Boxes	0	0	-	-	-	-	-	-	1	.20	0	0	0	0	0	0	2	.10	0	0	0	0	0	0
13 Rocker Arms	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
15 Cylinder Barrels	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
16 Oil Sump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
17 Oil Lines	8	.23	0	100	0	0	0	67	2	.40	0	100	0	0	0	50	0	0	-	-	-	-	-	-
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	2	.10	0	100	0	100	0	100
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	0	0	-	-	-	-	-	-	1	.20	0	0	0	0	0	0	0	0	-	-	-	-	-	-
22 Intake Tubes	2	.06	0	0	0	0	0	0	2	.40	100	100	100	100	100	100	1	.05	0	0	0	0	0	0
23 Carburetor	2	.06	0	25	0	25	0	25	2	.40	100	100	100	100	100	100	2	.10	0	5	0	0	0	5
24 Accessories-Starter Generator, Filter, Oil Pump	0	0	-	-	-	-	-	-	1	.20	0	0	0	0	0	0	0	0	-	-	-	-	-	-
25 Fuel Lines	2	.06	100	100	100	100	100	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
26 Control Linkages	0	0	-	-	-	-	-	-	1	.20	100	100	100	100	100	100	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
Functional Components																								
A Lub. System	8	.23	0	100	0	100	0	100	3	.60	0	100	0	0	0	33	5	.24	0	100	0	0	0	40
B Mech. Power Losses	0	0	-	-	-	-	-	-	2	.40	0	2	0	0	0	1	2	.10	0	5	0	2	0	4
C Exhaust System	0	0	-	-	-	-	-	-	1	.20	0	0	0	0	0	0	0	0	-	-	-	-	-	-
D Induction System	6	.17	100	100	0	0	25	41	2	.40	100	100	100	100	100	100	2	.10	0	5	0	0	0	3
E Ignition & Magnetos	0	0	-	-	-	-	-	-	1	.20	0	2	0	2	0	2	2	.10	0	5	0	2	0	4
F Control Damage Affecting Engine Performance	7	.20	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-

TABLE C15

ENGINE COMPONENT DAMAGE
B-25 Front and Above = 20°, = 13°

Caliber / Component	Cal .50 API-T, M20 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm HEI M97 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm Inc. M96 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Component																								
1 Propeller	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
3 Prop. Governor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section Inc. Reduction Gears, Cams, etc	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	1	.07	0	100	0	100	0	100	1	.06	78	100	78	100	78	100
8 Ignition Leads	5	.31	0	5	0	0	0	1	5	.36	0	100	0	0	0	21	1	.06	0	0	0	0	0	0
9 Spark Plugs	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
10 Push Rods	2	.13	0	100	0	100	0	100	1	.07	0	10	0	10	0	10	0	0	-	-	-	-	-	-
11 Push Rod Covers	1	.06	0	0	0	0	0	0	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
12 Rocker Boxes	0	0	-	-	-	-	-	-	2	.14	0	0	0	0	0	0	0	0	-	-	-	-	-	-
13 Rocker Arms	1	.06	0	3	0	3	0	3	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	2	.13	0	5	0	3	0	4	0	0	-	-	-	-	-	-	2	.12	0	5	0	5	0	5
15 Cylinder Barrels	1	.06	0	5	0	5	0	5	2	.14	0	10	0	0	0	5	0	0	-	-	-	-	-	-
16 Oil Sump	0	0	-	-	-	-	-	-	4	.29	0	18	0	0	0	10	0	0	-	-	-	-	-	-
17 Oil Lines	2	.13	0	100	0	0	0	50	0	0	-	-	-	-	-	-	1	.06	0	7	0	7	0	7
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
19 Crank Case, Connecting Rods & Crankshaft	2	.13	0	0	0	0	0	0	1	.07	0	0	0	0	0	0	3	.18	78	100	0	0	26	36
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
22 Intake Tubes	0	0	-	-	-	-	-	-	1	.07	0	5	0	5	0	5	0	0	-	-	-	-	-	-
23 Carburetor	1	.06	100	100	100	100	100	100	0	0	-	-	-	-	-	-	1	.06	75	100	75	100	75	100
24 Accessories-Starter Generator, Filter, Oil Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
25 Fuel Lines	1	.06	0	30	0	30	0	30	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	2	.13	0	100	0	100	0	100	0	0	-	-	-	-	-	-	2	.12	0	100	0	100	0	100
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
Functional Component																								
A Lub. System	7	.44	0	100	0	0	0	58	2	.14	0	0	0	0	0	0	4	.24	78	100	0	70	20	92
B Mech. Power Losses	6	.38	0	10	0	0	0	5	8	.57	0	18	0	0	0	7	4	.24	0	10	0	0	0	5
C Exhaust System	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
D Induction System	2	.13	100	100	0	3	50	52	1	.07	0	5	0	5	0	5	1	.06	75	100	75	100	75	100
E Ignition & Magnetos	5	.31	0	6	0	0	0	1	7	.50	0	100	0	0	0	44	3	.18	78	100	0	0	26	33
F Control Damage Affecting Engine Performance	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-

TABLE C16

ENGINE COMPONENT DAMAGE

P-38 Front and Below = 20°, = 13° — P-38 Rear and Above, = 20°, = 13°

Caliber: Cal .50 API-T, M20; Cal .60 API, T39; Cal .60 Inc. T36E2 (front and below) — Cal .50 API-T, M20; Cal .60 API, T39; Cal .60 Inc. T36E2 (rear and above). Each: No. Hits, P_h, Assessments Max., Min., Aver. (A, B)

Component	Data
Physical Component	
1 Propeller	[illegible]
2 Prop. Junction Box and Cable	[illegible]
3 Prop. Governor	[illegible]
4 Nose Section, Inc. Reduction Gears, Cams, Etc.	[illegible]
5 Scavenging Pump	[illegible]
6 Magneto	[illegible]
7 Ignition Harness	[illegible]
8 Ignition Leads	[illegible]
9 Spark Plugs	[illegible]
10 Push Rods	[illegible]
11 Push Rod Covers	[illegible]
12 Rocker Boxes	[illegible]
13 Rocker Arms	[illegible]
14 Cylinder Heads	[illegible]
15 Cylinder Barrels	[illegible]
16 Oil Sump	[illegible]
17 Oil Lines	[illegible]
18 Oil Coolers	[illegible]
19 Crank Case, Connecting Rods & Crankshaft	[illegible]
20 Blower	[illegible]
21 Exhaust Tubes	[illegible]
22 Intake Tubes	[illegible]
23 Carburetor	[illegible]
24 Accessories-Starter Generator, Filter, Oil Pump	[illegible]
25 Fuel Lines	[illegible]
26 Control Linkages	[illegible]
27 Prop. Dome or Pitch Controlling Motor	[illegible]
28 Oil Tanks	[illegible]
29 Coolant Cooler	[illegible]
30 Coolant Line	[illegible]
31 Coolant Tank	[illegible]
32 Intake Manifold	[illegible]
33 Cylinder Coolant Jacket	[illegible]
Functional Component	
A Lub. System	[illegible]
B Mech. Power Losses	[illegible]
C Exhaust System	[illegible]
D Induction System	[illegible]
E Ignition & Magnetos	[illegible]
F Control Damage Affecting Engine Performance	[illegible]

TABLE C17

ENGINE COMPONENT DAMAGE

P-47 Front Below, = 20°, = 7°

Caliber / Component	Cal .50 API-T, M20 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .60 API T39 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm HEI M97 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Component																								
1 Propeller	16	.25	0	0	0	0	0	0	6	.29	0	0	0	0	0	0	2	.13	0	0	0	0	0	0
2 Prop. Junction Box and Cable	1	.02	0	0	0	0	0	0	1	.05	0	10	0	10	0	10	2	.13	0	1	0	1	0	1
3 Prop. Governor	1	.02	0	100	0	0	0	100	0	0	-	-	-	-	-	-	1	.06	0	0	0	0	0	0
4 Nose Section, Inc. Reduction Gears, Cams, etc.	4	.06	0	2	0	1	0	2	0	0	-	-	-	-	-	-	1	.06	0	0	0	0	0	0
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.06	0	100	0	100	0	100
6 Magneto	3	.05	0	5	0	0	0	3	1	.05	0	0	0	0	0	0	0	0	-	-	-	-	-	-
7 Ignition Harness	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
8 Ignition Leads	9	.14	0	3	0	0	0	2	7	.33	0	0	0	0	0	0	7	.44	0	0	0	0	0	0
9 Spark Plugs	2	.03	0	0	0	0	0	0	3	.14	0	3	0	0	0	1	0	0	-	-	-	-	-	-
10 Push Rods	3	.05	0	0	0	0	0	0	0	0	-	-	-	-	-	-	3	.19	0	25	0	0	0	8
11 Push Rod Covers	4	.06	0	3	0	0	0	2	4	.19	0	6	0	6	0	6	7	.44	0	40	0	0	0	5
12 Rocker Boxes	10	.16	0	2	0	0	0	1	6	.29	0	2	0	0	0	0	2	.13	0	1	0	1	0	1
13 Rocker Arms	0	0	-	-	-	-	-	-	1	.05	0	80	0	80	0	80	0	0	-	-	-	-	-	-
14 Cylinder Heads	4	.06	0	3	0	2	0	2	5	.24	0	5	0	5	0	5	1	.06	0	0	0	0	0	0
15 Cylinder Barrels	4	.06	0	3	0	2	0	2	2	.10	0	0	0	0	0	0	2	.13	0	3	0	0	0	2
16 Oil Sump	0	0	-	-	-	-	-	-	1	.05	0	100	0	100	0	100	0	0	-	-	-	-	-	-
17 Oil Lines	5	.08	0	2	0	0	0	0	2	.10	0	2	0	2	0	2	2	.13	0	100	0	0	0	50
18 Oil Coolers	3	.05	10	100	0	2	5	75	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
19 Crank Case, Connecting Rods & Crankshaft	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
20 Blower	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
21 Exhaust Tubes	2	.03	0	2	0	1	0	1	2	.10	0	0	0	0	0	0	0	0	-	-	-	-	-	-
22 Intake Tubes	1	.02	0	2	0	2	0	2	2	.10	0	0	0	0	0	0	0	0	-	-	-	-	-	-
23 Carburetor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
24 Accessories-Starter Generator, Filter, Oil Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
25 Fuel Lines	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
27 Prop. Dome or Pitch Controlling Motor	2	.03	0	10	0	0	0	5	0	0	-	-	-	-	-	-	1	.06	0	5	0	5	0	5
28 Oil Tanks	0	0	-	-	-	-	-	-	2	.10	0	0	0	0	0	0	0	0	-	-	-	-	-	-

TABLE C18

ENGINE COMPONENT DAMAGE
B-17 Front = 20°, = 7°

Caliber / Component	Cal .50 API-T, M20 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	Cal .50 API, T39 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B	20mm HEI, M97 No. Hits	P_h	Max. A	Max. B	Min. A	Min. B	Aver. A	Aver. B
Physical Component																								
1 Propeller	15	.42	0	0	0	0	0	0	6	.26	0	0	0	0	0	0	4	.21	0	0	0	0	0	0
2 Prop. Junction Box and Cable	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	0	0	0	0	0	0
3 Prop. Governor	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
4 Nose Section, Inc. Reduction Gears, Cams, etc	5	.14	0	5	0	0	0	3	3	.14	0	10	0	0	0	3	2	.11	0	0	0	0	0	0
5 Scavenging Pump	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
6 Magneto	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
7 Ignition Harness	2	.06	0	0	0	0	0	0	1	.04	0	0	0	0	0	0	1	.05	0	0	0	0	0	0
8 Ignition Leads	3	.08	0	0	0	0	0	0	3	.14	0	8	0	2	0	3	5	.26	0	0	0	0	0	0
9 Spark Plugs	1	.03	0	5	0	5	0	5	1	.04	0	0	0	0	0	0	0	0	-	-	-	-	-	-
10 Push Rods	4	.11	0	0	0	0	0	0	2	.10	0	5	0	4	0	5	3	.16	0	100	0	0	0	55
11 Push Rod Covers	3	.08	0	0	0	0	0	0	4	.19	0	5	0	0	0	1	7	.37	10	15	0	4	1	5
12 Rocker Boxes	1	.03	0	5	0	5	0	5	0	0	-	-	-	-	-	-	1	.05	0	6	0	6	0	6
13 Rocker Arms	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
14 Cylinder Heads	0	0	-	-	-	-	-	-	1	.04	0	0	10	0	0	0	1	.05	0	5	0	5	0	5
15 Cylinder Barrels	3	.08	0	4	0	0	0	2	6	.26	0	5	0	0	0	1	1	.05	0	0	0	0	0	0
16 Oil Pump	1	.03	0	50	0	50	0	50	3	.14	100	100	0	100	50	100	1	.05	0	100	0	100	0	100
17 Oil Lines	4	.11	0	100	0	0	0	50	2	.10	0	0	0	0	0	0	3	.16	0	60	0	0	0	20
18 Oil Coolers	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
19 Crank Case, Connecting Rods & Crankshaft	2	.06	0	0	0	0	0	0	1	.04	0	100	0	100	0	100	0	0	-	-	-	-	-	-
20 Blower	1	.03	0	2	0	2	0	2	1	.04	0	50	0	50	0	50	0	0	-	-	-	-	-	-
21 Exhaust Tubes	5	.14	0	0	0	0	0	0	1	.04	0	0	0	0	0	0	1	.05	0	0	0	0	0	0
22 Intake Tubes	2	.06	0	0	0	0	0	0	3	.14	100	100	0	0	50	50	5	.26	0	100	0	0	0	40
23 Carburetor	1	.03	100	100	100	100	100	100	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-
24 Accessories-Starter Generator, Filter, Oil Pump	0	0	-	-	-	-	-	-	1	.04	0	2	0	2	0	2	0	0	-	-	-	-	-	-
25 Fuel Lines	2	.06	100	100	0	0	50	50	0	0	-	-	-	-	-	-	1	.05	0	20	0	20	0	20
26 Control Linkages	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	1	.05	0	0	0	0	0	0
27 Prop. Dome or Pitch Controlling Motor	3	.08	5	100	0	0	3	60	1	.04	0	0	0	0	0	0	1	.05	0	100	0	100	0	100
28 Oil Tanks	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-	0	0	-	-	-	-	-	-

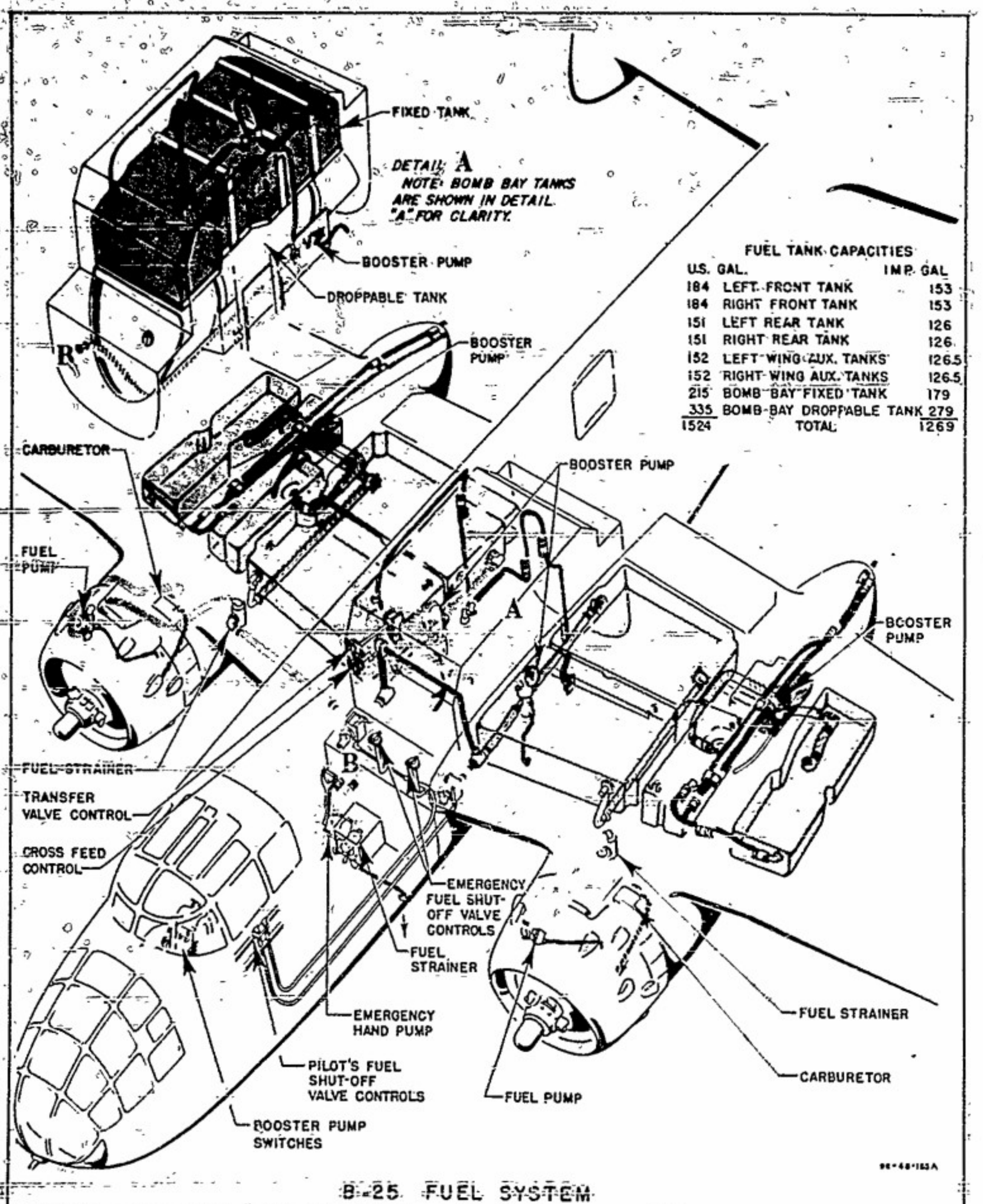
TABLE C19

ENGINE COMPONENT DAMAGE, ALL CALIBERS TOTALED

Engine / Physical Component	P-47 Front Below	B-17 Front Below	P-38 Front Below	B-25 Front Below	B-25 Rear Below	B-29 Rear Above	P-38 Rear Above	B-25 Front Above
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Appendix D

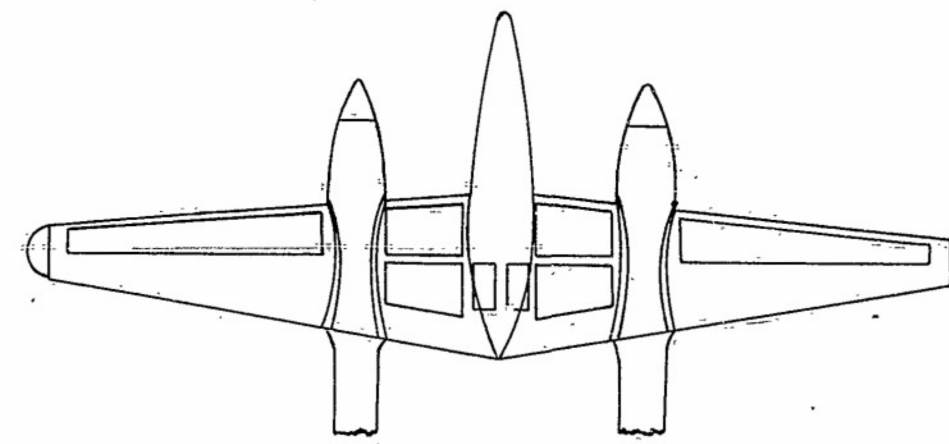
ILLUSTRATIONS OF FUEL SYSTEMS



FUEL TANK CAPACITIES

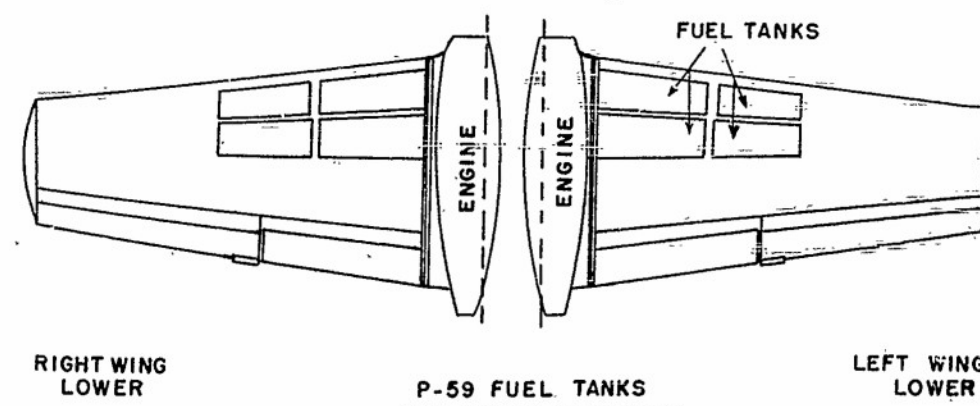
U.S. GAL.		IMP. GAL
184	LEFT FRONT TANK	153
184	RIGHT FRONT TANK	153
151	LEFT REAR TANK	126
151	RIGHT REAR TANK	126
152	LEFT WING AUX. TANKS	126.5
152	RIGHT WING AUX. TANKS	126.5
215	BOMB BAY FIXED TANK	179
335	BOMB-BAY DROPPABLE TANK	279
1524	TOTAL	1269

Figure D1 - B-25 Fuel System.



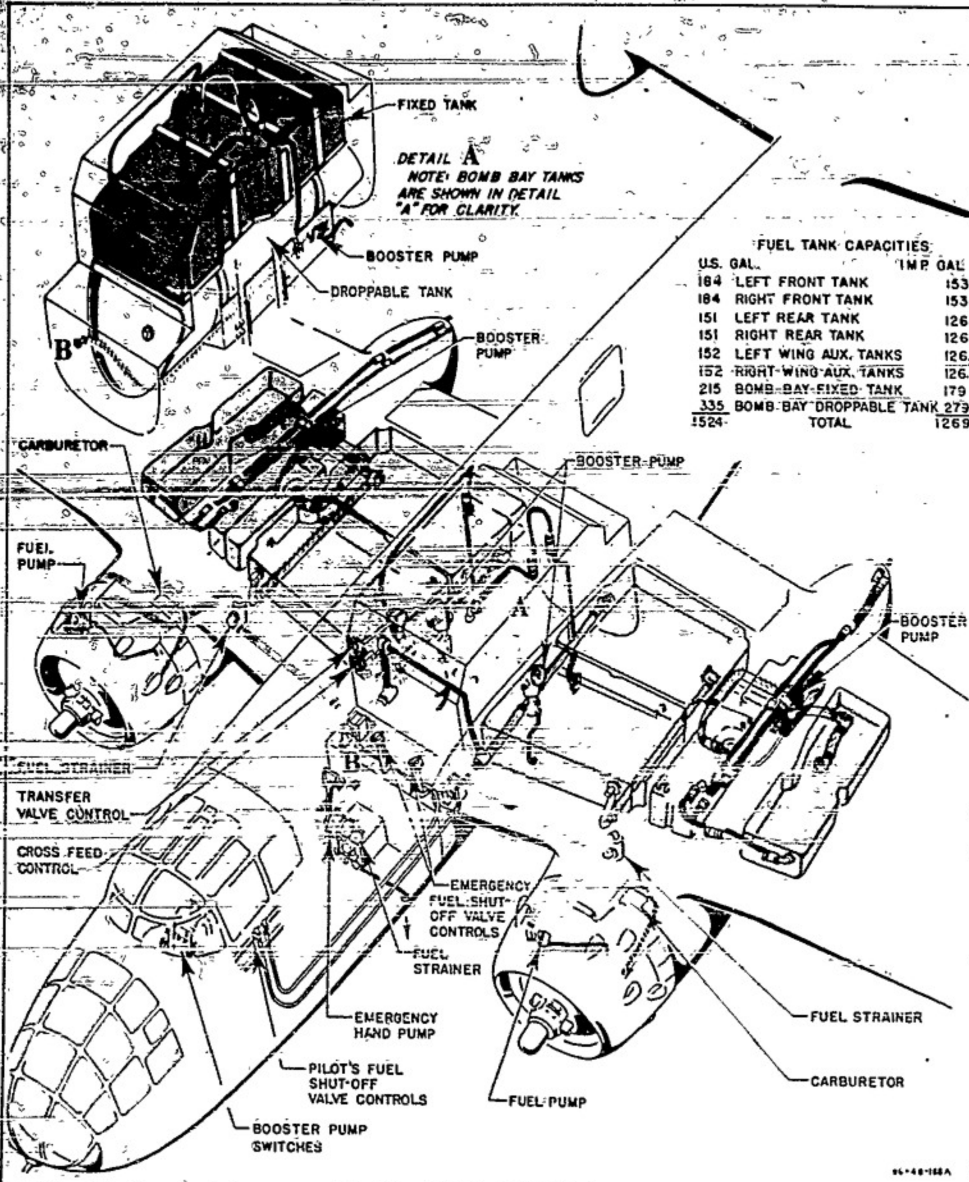
P-38 FUEL TANKS
AND ENGINE NACELLE

FIG. D2



P-59 FUEL TANKS
AND ENGINE POSITIONS

FIG. D3

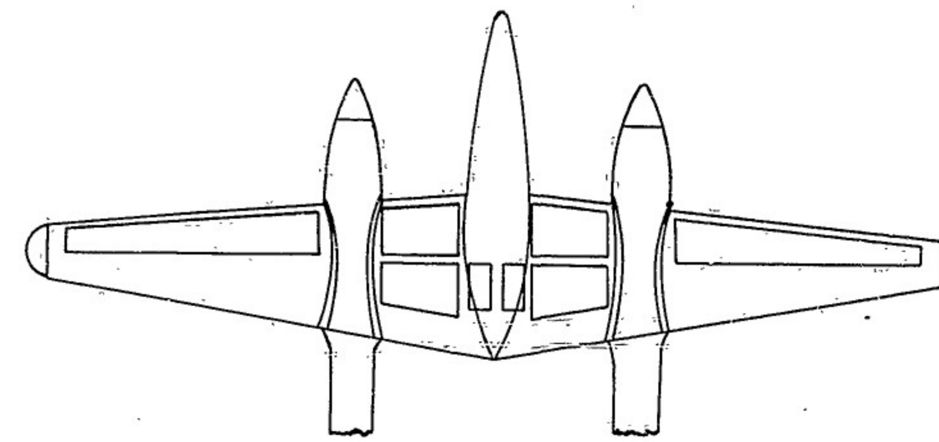


FUEL TANK CAPACITIES

U.S. GAL.		IMP. GAL.
184	LEFT FRONT TANK	153
184	RIGHT FRONT TANK	153
151	LEFT REAR TANK	126
151	RIGHT REAR TANK	126
152	LEFT WING AUX. TANKS	126.5
152	RIGHT WING AUX. TANKS	126.5
215	BOMB BAY FIXED TANK	179
335	BOMB BAY DROPPABLE TANK	279
1524	TOTAL	1269

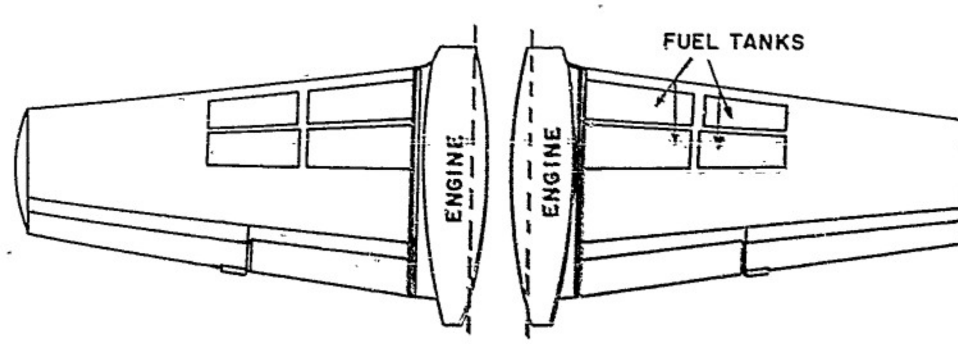
B-25 FUEL SYSTEM

Figure D1 - B-25 Fuel System.



P-38 FUEL TANKS
AND ENGINE NACELLE

FIG. D2



RIGHT WING LOWER

LEFT WING LOWER

P-59 FUEL TANKS
AND ENGINE POSITIONS

FIG. D3

Appendix E

TABLES RELATED TO FUEL CELL DAMAGE

TABLE E1

Single Skin Fuel Tank Ignition and Leakage

Range: 500 Yards — Rear, Above θ = 20°, ø = 13°

Ammunition	Type Fuel	Target	Hits Proj. Area H_{sc}	Penetration of Cell CP_{sc}	Hits Causing Fires F_{sc}	Leakage No Fire L_{sc}	$\frac{F_{sc}}{H_{sc}}$	$\frac{L_{sc}}{H_{sc}}$	$\frac{CP_{sc}}{H_{sc}}$	$\frac{F_{sc}}{CP_{sc}}$	$\frac{L_{sc}}{CP_{sc}}$	Average Assessments Fire $\bar{A}_{F_{sc}}$	$\bar{B}_{F_{sc}}$	Leakage, no fire $\bar{A}_{L_{sc}}$	$\bar{B}_{L_{sc}}$
Cal. .50, Inc, M23	Gasoline	A35	0	-	-	-	-	-	-	-	-	-	-	-	-
		B25	0	-	-	-	-	-	-	-	-	-	-	-	-
		P38	0	-	-	-	-	-	-	-	-	-	-	-	-
		Total	0	-	-	-	-	-	-	-	-	-	-	-	-
	Kerosene	P38	14	11	2	3	.143	.214	.786	.182	.273	[illegible]	[illegible]	[illegible]	[illegible]
		P59	0	-	-	-	-	-	-	-	-	-	-	-	-
		Total	14	11	2	3	.143	.214	.786	.182	.273	[illegible]	[illegible]	[illegible]	[illegible]
	*Empty	B25	0	-	-	-	-	-	-	-	-	-	-	-	-
Cal. .50, API-T, M20	Gasoline	A35	6	6	4	0	.667	.000	1.000	.667	[illegible]	[illegible]	[illegible]	-	-
		B25	37	28	4	7	.108	.189	.757	.143	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		P38	13	6	4	1	[illegible]	.077	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Total	56	43	12	8	.214	.143	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	13	12	0	5	.000	.385	.923	.000	.417	-	-	[illegible]	[illegible]
		P59	0	-	-	-	-	-	-	-	-	-	-	-	-
		Total	13	12	0	5	.000	.385	.923	.000	.417	-	-	[illegible]	[illegible]
	*Empty	B25	55	31	-	-	-	-	.564	-	-	-	-	-	-
Cal. .60, API, T39	Gasoline	A35	5	5	3	1	.600	.200	1.000	.600	.200	[illegible]	[illegible]	[illegible]	[illegible]
		B25	15	15	5	4	.333	.267	1.000	.333	.267	[illegible]	[illegible]	[illegible]	[illegible]
		P38	17	13	4	7	.235	.412	.765	.308	.538	[illegible]	[illegible]	[illegible]	[illegible]
		Total	37	33	12	12	.324	.324	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	8	7	0	2	.000	.250	.875	.000	.286	-	-	[illegible]	[illegible]
		P59	7	7	2	5	.286	.714	1.000	.286	.714	[illegible]	[illegible]	[illegible]	[illegible]
		Total	15	14	2	7	.133	.437	[illegible]	.143	.500	[illegible]	[illegible]	[illegible]	[illegible]
	*Empty	B25	34	28	-	-	-	-	.824	-	-	-	-	-	-
Cal. .60, Inc, T36E2	Gasoline	A35	0	-	-	-	-	-	-	-	-	-	-	-	-
		B25	8	8	3	3	.375	.375	1.000	.375	.375	[illegible]	[illegible]	[illegible]	[illegible]
		P38	11	11	6	2	.545	.182	1.000	.545	.182	[illegible]	[illegible]	[illegible]	[illegible]
		Total	19	19	9	5	.474	.263	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	10	10	5	2	.500	.200	1.000	.500	.200	[illegible]	[illegible]	[illegible]	[illegible]
		P59	8	5	3	1	.375	.125	.625	.600	.200	[illegible]	[illegible]	[illegible]	[illegible]
		Total	18	15	8	3	.444	.167	.833	.533	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	*Empty	B25	39	31	-	-	-	-	.795	-	-	-	-	-	-
20 MM, HEI, M97	Gasoline	A35	4	4	3	1	.750	.250	1.000	.750	.250	[illegible]	[illegible]	[illegible]	[illegible]
		B25	6	6	3	2	.500	.333	1.000	.500	.333	[illegible]	[illegible]	[illegible]	[illegible]
		P38	17	14	11	2	.647	[illegible]	.824	[illegible]	.143	[illegible]	[illegible]	[illegible]	[illegible]
		Total	27	24	17	5	.630	.185	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	14	10	4	6	.286	.429	.714	.400	.600	[illegible]	[illegible]	[illegible]	[illegible]
		P59	6	6	3	1	.500	.167	1.000	.500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		Total	20	16	7	7	.350	.350	.800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	*Empty	B25	31	25	-	-	-	-	.806	-	-	-	-	-	-
20 MM, Inc, M96	Gasoline	A35	0	-	-	-	-	-	-	-	-	-	-	-	-
		B25	5	4	2	0	[illegible]	.000	.800	.500	.000	[illegible]	[illegible]	-	-
		P38	10	10	7	1	.700	.100	1.000	.700	.100	[illegible]	[illegible]	-	-
		Total	15	14	9	1	.600	[illegible]	.933	.643	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	5	5	2	0	.400	.000	1.000	.400	.000	[illegible]	[illegible]	-	-
		P59	10	10	3	7	.300	.700	1.000	.300	.700	[illegible]	[illegible]	[illegible]	[illegible]
		Total	15	15	5	7	.333	.467	1.000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	*Empty	B25	11	6	-	-	-	-	.545	-	-	-	-	-	-
3 CM, (German) HE, MK108	Gasoline	A35	0	-	-	-	-	-	-	-	-	-	-	-	-
		B25	2	2	2	0	1.000	.000	1.000	1.000	.000	[illegible]	[illegible]	-	-
		P38	13	11	9	1	[illegible]	.077	.846	.818	.091	[illegible]	[illegible]	-	-
		Total	15	13	11	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	3	3	1	1	.333	.333	1.000	.333	.333	1.000	[illegible]	[illegible]	[illegible]
		P59	0	-	-	-	-	-	-	-	-	-	-	-	-
		Total	3	3	1	1	[illegible]	[illegible]	1.000	[illegible]	[illegible]	1.000	[illegible]	[illegible]	[illegible]
	*Empty	B25	6	4	-	-	-	-	.667	-	-	-	-	-	-
37 MM, HE, M54	Gasoline	A35	0	-	-	-	-	-	-	-	-	-	-	-	-
		B25	4	3	3	0	[illegible]	[illegible]	[illegible]	1.000	.000	[illegible]	[illegible]	-	-
		P38	15	10	7	1	[illegible]	[illegible]	[illegible]	.700	.100	[illegible]	[illegible]	-	-
		Total	19	13	10	1	[illegible]	[illegible]	.684	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Kerosene	P38	0	-	-	-	-	-	-	-	-	-	-	-	-
		P59	0	-	-	-	-	-	-	-	-	-	-	-	-
		Total	0	-	-	-	-	-	-	-	-	-	-	-	-
	*Empty	B25	14	12	-	-	-	-	.857	-	-	-	-	-	-

*Empty - From structure firings, tabulated to get probability of cell penetration for hits on projected area of cell.

TABLE E2

Compound Fuel Tank Ignition, Firing Into Damaged Tanks

Range: 500 Yards — Rear, Above θ = 20°, ø = 13°

Ammunition	Type Fuel	Target	Compound Hits on Proj. Area H_c	Cell Penetration Comp. Hits CP_c	Hits Causing Fires F_c	$\frac{F_c}{H_c}$	$\frac{CP_c}{H_c}$	$\frac{F_c}{CP_c}$	$\bar{A}_{F_c}$	$\bar{B}_{F_c}$
3 CM, (German) HE MK 108	Gasoline	A35	0	-	-	-	-	-	-	-
		B25	2	2	2	1.000	1.000	1.000	1.000	1.000
		P38	2	1	1	.500	.500	1.000	.000	.000
		Total	4	3	3	.750	.750	1.000	.667	.667
	Kerosene	P38	4	4	4	1.000	1.000	1.000	1.000	1.000
		P59	0	-	-	-	-	-	-	-
		Total	4	4	4	1.000	1.000	1.000	1.000	1.000
	*Empty	B25	6	4	-	-	.667	-	-	-
37 MM, HE, M54	Gasoline	A35	0	-	-	-	-	-	-	-
		B25	0	-	-	-	-	-	-	-
		P38	0	-	-	-	-	-	-	-
		Total	0	-	-	-	-	-	-	-
	Kerosene	P38	0	-	-	-	-	-	-	-
		P59	0	-	-	-	-	-	-	-
		Total	0	-	-	-	-	-	-	-
	*Empty	B25	14	12	-	-	.857	-	-	-
Cal. .50, Inc, M23	Kerosene	P38	4	4	3	.750	1.000	.750	.333	.667
Cal. .50, API-T, M20	Gasoline	A35	0	-	-	-	-	-	-	-
		B25	13	13	8	.615	1.000	.615	.125	.775
		P38	12	11	9	.750	.917	.819	.000	.800
		Total	25	24	17	.680	.960	.708	.059	.788
	Kerosene	P38	14	13	10	.714	.928	.929	.000	.680
		P59	0	-	-	-	-	-	-	-
		Total	14	13	10	.714	.928	.929	.000	.680
	*Empty	B25	55	31	-	-	.564	-	-	-
Cal. .60 API, T39	Gasoline	A35	1	1	1	1.000	1.000	1.000	.250	.650
		B25	10	10	10	1.000	1.000	1.000	.137	.663
		P38	13	13	5	.385	1.000	.385	.700	.870
		Total	24	24	16	.808	1.000	.808	.320	.852
	Kerosene	P38	3	3	2	.667	1.000	.667	1.000	1.000
		P59	6	6	2	.333	1.000	.333	.000	.600
		Total	9	9	4	.444	1.000	.444	.500	.800
	*Empty	B25	34	28	-	-	.824	-	-	-
Cal. .60 Inc, T36 E2	Gasoline	A35	0	-	-	-	-	-	-	-
		B25	8	8	8	1.000	1.000	1.000	.125	.775
		P38	17	17	12	.706	1.000	.706	.250	.520
		Total	25	25	20	.800	1.000	.800	.200	.622
Cal. .60 Inc, T36 E2	Kerosene	P38	3	3	2	.667	1.000	.667	1.000	1.000
		P59	3	3	2	.667	1.000	.667	.825	1.000
		Total	6	6	4	.667	1.000	.667	.913	1.000
	*Empty	B25	39	31	-	-	.795	-	-	-
20 MM, HEI, M97	Gasoline	A35	2	2	2	1.000	1.000	1.000	.375	1.000
		B25	3	3	3	1.000	1.000	1.000	.667	1.000
		P38	8	8	7	.833	1.000	.833	.357	.742
		Total	13	13	12	.902	1.000	.902	.437	.849
	Kerosene	P38	2	2	2	1.000	1.000	1.000	.000	.875
		P59	1	1	1	1.000	1.000	1.000	.000	1.000
		Total	3	3	3	1.000	1.000	1.000	.000	.917
	*Empty	B25	31	25	-	-	.806	-	-	-
20 MM, Inc, M96	Gasoline	A35	0	-	-	-	-	-	-	-
		B25	5	5	5	1.000	1.000	1.000	.667	.833
		P38	8	8	6	.750	1.000	.750	.833	1.000
		Total	13	13	11	.846	1.000	.846	.758	.924
	Kerosene	P38	1	1	1	1.000	1.000	1.000	1.000	1.000
		P59	3	3	3	1.000	1.000	1.000	.667	1.000
		Total	4	4	4	1.000	1.000	1.000	.750	1.000
	*Empty	B25	11	6	-	-	.545	-	-	-

*Empty - From structure firings, tabulated to get probability of cell penetration for hits on projected area of cell.

Appendix F

TABLES RELATED TO STRUCTURAL DAMAGE AND PILOT INJURY

TABLE F1

Structure Damage by Zone for the B-25 (Excluding Personnel)

Rear & Above

	Cal. .50 API-T, M20				Cal. 60, INC, T36E2				Cal. 60 API T39				20mm, HEI M97				20mm, INC M96			
	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B
F1	6	0	.000	.000	3	0	.000	.000	4	0	.000	.000	3	0	.000	.000	2	0	.000	.000
F2	11	0	.000	.000	6	0	.000	.000	5	0	.000	.000	4	0	.000	.000	4	0	.000	.000
3	19	0	.000	.000	11	0	.020	.020	9	0	.033	.053	4	0	.000	.000	5	0	.156	.180
4	22	0	.000	.000	10	0	.018	.018	10	0	.010	.030	7	0	.000	.000	8	0	.000	.000
5	13	0	.000	.000	10	0	.000	.000	9	0	.000	.000	9	0	.000	.015	4	0	.000	.000
6	12	0	.000	.000	10	0	.000	.000	6	0	.000	.000	8	0	.000	.000	4	0	.000	.000
7	21	0	.030	.000	14	0	.010	.010	14	0	.000	.000	8	0	.000	.000	6	0	.000	.000
8	17	0	.000	.000	6	0	.000	.000	7	0	.000	.000	6	0	.000	.000	4	0	.000	.000
9	7	0	.000	.000	2	0	.000	.000	3	0	.000	.000	1	0	.000	.000	[illegible]	0	.000	.000
10	3	0	.000	.000	1	0	.000	.000	4	0	.000	.000	2	0	.000	.000	1	0	.000	.000
11	8	0	.000	.000	6	0	.000	.000	11	0	.000	.077	5	0	.000	.000	6	0	.000	.000
W1	17	0	.000	.000	8	0	.000	.500	6	0	.000	.000	7	0	.000	.000	4	0	.000	.396
2	16	0	.000	.000	8	0	.000	.000	11	0	.000	.000	8	0	.018	.100	5	0	.000	.125
3	20	0	.000	.000	8	0	.000	.000	16	0	.000	.000	9	0	.016	.100	6	0	.000	.275
4	22	0	.000	.000	8	0	.000	.000	26	0	.000	.000	11	0	.000	.000	8	0	.000	.000
5	14	0	.003	.000	10	0	.000	.000	18	0	.000	.000	15	0	.000	.000	7	0	.000	.224
6	8	0	.000	.000	11	0	.080	.269	17	0	.000	.000	14	0	.016	.078	7	0	.000	.000
7	30	0	.000	.000	14	0	.000	.000	24	0	.000	.000	12	0	.000	.041	12	0	.950	1.000
8	22	0	.000	.000	9	0	.000	.000	20	0	.013	.025	11	0	.000	.000	10	0	.000	.000
9	13	0	.000	.000	6	0	.000	.000	23	0	.000	.000	9	0	.016	.033	7	0	.025	.374
10	13	0	.000	.000	7	0	.000	.000	16	0	.000	.000	13	0	.000	.050	10	0	.050	.490
11	16	0	.000	.000	8	0	.000	.000	12	0	.000	.000	9	0	.000	.000	8	0	.024	.096
12	16	0	.000	.000	10	0	.000	.000	10	0	.000	.150	7	0	.000	.000	4	0	.000	.032
LHT	28	0	.000	.000	17	0	.000	1.000	39	0	.000	.000	22	0	.750	1.100	20	0	.460	1.020
LVT	16	0	.000	.000	16	0	.000	.000	13	0	.000	.000	29	0	.05	.100	16	0	.000	.048
RHT	18	0	.000	.000	8	0	.000	.000	12	0	.000	.036	0	-	-	-	0	-	-	-
RVT	21	0	.000	.000	10	0	.000	.000	17	0	.085	.323	0	-	-	-	0	-	-	-
TOTAL	429	0	.000	.000	245	0	.098	1.817	342	0	.140	.594	243		.864	1.637	169		1.659	4.480

	3cm MK108M				37mm HE, M54				75 mm, HE M48				105mm HE M1			
	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B
F1	0	0	-	-	3	0	.000	.000	0	0	-	-	0	0	-	-
F2	1	0	.000	.000	2	0	.000	.000	0	0	-	-	0	0	-	-
3	1	1	1.000	1.000	2	0	.000	.000	1	1	1.000	1.000	0	0	-	-
4	1	0	.000	.000	1	0	.000	.000	1	0	.700	1.000	0	0	-	-
5	1	0	.000	.000	3	0	.000	.078	0	0	-	-	0	0	-	-
6	1	0	.000	.000	5	0	.000	.050	0	0	-	-	0	0	-	-
7	2	0	.000	.000	2	0	.000	.056	0	0	-	-	0	0	-	-
8	2	0	.000	.076	2	0	.000	.034	2	2	2.000	2.000	1	1	1.000	1.000
9	0	0	-	-	0	0	-	-	0	0	-	-	0	0	-	-
10	0	0	-	-	2	0	.016	.154	0	0	-	-	0	0	-	-
11	2	0	.000	.000	2	0	.000	.000	0	0	-	-	0	0	-	-
W1	2	0	.000	.172	1	0	.000	.006	0	0	-	-	1	0	.800	.408
2	0	0	-	-	1	0	.000	.130	0	0	-	-	0	0	.600	.000
3	0	0	-	-	1	0	.096	.986	0	0	-	-	0	0	-	-
4	1	0	.016	.366	2	0	.000	.190	2	1	2.000	2.000	0	0	-	-
5	3	0	.000	.000	3	0	.054	.117	0	0	-	-	0	0	-	-
6	5	0	.000	.000	3	0	.000	.000	2	0	.132	1.454	1	1	1.000	1.000
7	4	0	.000	.000	4	0	.000	.000	2	1	1.600	1.920	1	1	1.000	1.000
8	3	0	.000	.000	2	0	.000	.020	1	0	.000	.008	0	0	-	-
9	3	0	.280	.768	4	0	.000	.000	0	0	-	-	0	0	-	-
10	2	0	.040	.062	2	0	.054	.176	1	1	1.000	1.000	0	0	-	-
11	2	0	.656	.858	1	0	.333	.533	1	0	.900	1.000	1	1	1.000	1.000
12	0	0	-	-	2	0	.000	.040	0	0	-	-	1	1	1.000	1.000
LHT	0	0	-	-	4	0	.270	.460	2	2	2.000	2.000	0	0	-	-
LVT	1	0	.006	.199	2	0	.034	.084	0	0	-	-	0	0	-	-
RHT	2	0	.000	.000	3	0	.000	.050	1	1	1.000	1.000	0	0	-	-
RVT	1	0	.000	.042	2	0	.000	.050	0	0	-	-	0	0	-	-
TOTAL	44	1	2.022	3.503	57		.857	3.124	16	9	12.632	14.382	6	5	5.200	5.408

TABLE E2
STRUCTURE DAMAGE BY ZONE FOR B-25

FRONT AND BELOW
Excluding Personnel Damage

	Cal. .50, API-T, M20				Cal. 60, API, T39				Cal. 60, INC, T36E2				20MM, INC, M96			
	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B
F1	26	0	.000	.000	4	0	.000	.000	6	0	.000	.000	9	0	.000	.000
2	23	0	.000	.000	5	0	1.000	1.000	9	0	.050	1.000	5	0	.000	.000
3	6	0	.000	.000	3	0	.000	.000	8	0	.090	.000	9	0	.000	.000
4	8	0	.000	.000	5	0	1.000	1.000	6	0	.000	.000	7	0	1.000	1.000
5	6	0	.000	.000	5	0	1.000	1.000	4	0	.000	.000	9	0	.000	.000
6	2	0	.000	.000	4	0	.000	.000	2	0	.000	.000	4	0	.000	.000
7	6	0	.000	.000	4	0	.000	.000	7	0	.000	.000	4	0	.000	.000
8	4	0	.000	.000	3	0	.000	.000	5	0	.000	.000	4	0	.000	.000
9	1	0	.000	.000	2	0	.000	.000	5	0	.000	.000	4	0	.000	.000
10	0	-	-	-	0	-	-	-	1	0	.000	.000	0	-	-	-
11	0	-	-	-	0	-	-	-	1	0	.000	.000	1	0	.000	.000
W1	7	0	.000	.000	6	0	.000	.000	4	0	.000	.000	7	0	.000	.000
2	16	0	.000	.000	6	0	.000	.000	7	0	.000	.000	5	0	.000	.000
3	14	0	.000	.000	10	0	.003	.000	9	0	.000	.000	9	0	.000	.000
4	19	0	.030	.000	6	0	.000	.000	14	0	.000	.000	6	0	.000	1.000
5	7	0	.000	.000	0	-	-	-	13	0	.000	.000	3	0	.000	.000
6	15	0	.000	.000	9	0	.000	.000	10	0	1.000	1.000	13	0	.000	.000
7	0	-	-	-	1	0	.000	.000	11	0	.000	.000	1	0	.000	.000
8	5	0	.000	.000	0	-	-	-	0	-	-	-	1	0	.000	.000
9	10	0	.000	.000	10	0	.000	.000	6	0	.000	.000	10	0	.000	1.000
10	10	0	.000	.000	10	0	.000	.000	15	0	.000	.000	8	0	.000	.000
11	11	0	.000	.000	5	0	.000	.000	6	0	.000	.000	6	0	.000	.000
W12	4	0	.000	.000	4	0	.000	.000	2	0	.000	.000	4	0	.000	.000
LHT	1	0	.000	.000	0	-	-	-	0	-	-	-	0	-	-	-
LVT	0	-	-	-	1	0	.000	.000	0	-	-	-	2	0	.000	.000
RHT	4	0	.000	.000	3	0	.000	.000	8	0	.000	.000	3	0	.000	.000
RVT	5	0	.000	.000	7	0	.000	.000	7	0	.000	.000	8	0	.000	.000
TOTAL	210	0	.000	.000	113	0	3.000	3.000	163	0	1.030	2.000	142	0	1.000	3.000

	20MM HEI, M97				3cm, HE, MK108 (Ger.)				37mm, HE, M54				75 MM, HE 48			
	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B	Hits	K	A	B
F1	5	0	1.000	1.000	5	0	.000	.95	0	-	-	-	1	1	1.000	1.000
2	6	0	1.000	1.000	8	1	1.083	1.200	0	-	-	-	1	1	1.000	1.000
3	4	0	.000	.000	2	0	-	-	0	-	-	-	0	-	-	-
4	7	0	.000	.000	3	1	1.000	1.000	0	-	-	-	0	-	-	-
5	4	0	.000	.000	1	0	.000	.050	0	-	-	-	1	1	1.000	1.000
6	5	0	.000	.000	2	0	.000	.000	1	0	.000	.000	0	-	-	-
7	7	0	.000	.000	1	0	.000	.000	1	0	.000	.000	0	-	-	-
8	5	0	.000	.000	3	0	.450	1.280	0	-	-	-	1	1	1.000	1.000
9	3	0	.000	.000	2	0	.000	.075	1	0	.000	.000	0	-	-	-
10	2	0	.000	.000	0	-	-	-	0	-	-	-	0	-	-	-
11	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
W1	11	0	.000	.000	2	0	1.000	1.000	0	-	-	-	0	-	-	-
2	10	0	.000	.050	1	0	1.000	1.033	2	0	.000	.000	1	0	.000	.100
3	17	0	.000	.000	2	1	2.000	2.000	1	0	.000	1.000	1	1	1.000	1.000
4	11	0	.000	.000	3	0	.066	.376	1	0	.630	.960	0	0	-	-
5	12	0	.000	.000	4	0	.000	.049	0	-	-	-	0	-	-	-
6	13	0	.000	.000	2	0	.000	.650	1	0	.010	.430	2	0	1.000	1.230
7	1	0	.000	.000	3	0	.000	.250	0	-	-	-	0	-	-	-
8	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
9	11	0	.000	.000	5	0	1.016	1.900	1	0	.000	.000	1	1	1.000	1.000
10	11	0	.000	.000	1	0	.000	.000	1	0	.000	.000	0	-	-	-
11	9	0	.000	.000	3	1	1.950	2.000	1	0	.000	.000	1	1	1.000	1.000
W12	6	0	.000	.000	1	0	.000	.050	0	-	-	-	0	-	-	-
LHT	0	-	-	-	0	-	-	-	0	-	-	-	0	-	-	-
LVT	0	-	-	-	2	0	.000	.100	0	-	-	-	0	-	-	-
RHT	7	0	1.090	2.000	2	0	.000	.000	0	-	-	-	1	0	.200	.250
RVT	9	0	.000	.000	3	0	.000	.350	2	0	.000	.000	0	-	-	-
TOTAL	176	0	3.090	4.050	60	4	9.565	14.273	11	0	.790	2.390	11	7	8.200	8.580

TABLE F3

Overall Structural Damage (Excluding Personnel) for the B-25

Line of fire: Rear, Above $\theta = 20^\circ$, $\phi = 13^\circ$

Cal. and type of ammunition	No. of Hits H	No. of immediate Kills K	No. of "A" Kills A_i	Probability of an "A" Kill* (single shot) P_{A_s}	Upper Confidence Limit UCL (95%) $\bar{P}_{A_s}$	Lower Confidence Limit LCL (95%) $\underline{P}_{A_s}$	No. of "B" Kills B	Probability of a "B" Kill* (single shot) P_{B_s}	Upper Confidence Limit UCL (95%) $\bar{P}_{B_s}$	Lower Confidence Limit LCL (95%) $\underline{P}_{B_s}$
Cal. .50 API-T M20	429	0	.000	.000	.02	.00	.000	.000	.02	.00
Cal. .60 API T39	342	0	.135	.001	.02	.00	.683	.003	.02	.00
Cal. .60 INC, T36 E2	245	0	.098	.000	.02	.00	1.817	.009	.02	.00
20mm HEI M97	175	0	.860	.005	.03	.00	1.603	.010	.03	.00
20mm INC M96	169	0	1.660	.006	.03	.00	4.080	.020	.03	.00
3cm German M108	45	1	2.022	.015	.11	.00	3.503	.063	.17	.01
37mm HE M54	57	0	.854	.017	.10	.01	3.032	.059	.16	.02
75mm HE M48	16	9	12.530	.736	.90	.45	14.366	.842	.97	.57
105mm HE M1	6	5	5.200	.902	1.00	.45	5.405	.925	1.00	.47

*Weighted by relative areas of zones $P_{A_s} = \sum w_i \frac{A_i}{N_i}$

w_i = relative area of each zone
A_i = number of "A" kills in each zone due to structures
N_i = number of impacts in each zone
i = $F_1, F_2, \ldots, W_1, W_2, \ldots$, RVT, for all zones with recorded impacts.

TABLE F4

OVERALL STRUCTURAL DAMAGE (Excluding Personnel) FOR THE B-25

Line of Fire: Front, Below $\theta = 20^\circ$, $\phi = 13^\circ$

Ammun. Cal., Type	No. of Hits H	No. of immediate Kills K	No. of "A" Kills A	Prob. of an "A" Kill* P_{A_s}	Upper Confidence Limit UCL(95%) $\bar{P}_{A_s}$	Lower Confidence Limit LCL(95%) $\underline{P}_{A_s}$	No. of "B" Kills B	Prob. of a "B" Kill* P_{B_s}	Upper Confidence Limit UCL(95%) $\bar{P}_{B_s}$	Lower Confidence Limit LCL(95%) $\underline{P}_{B_s}$
Cal. 0.50 API-T M20	210	0	.000	.000	.03	.00	.000	.000	.03	.00
Cal. 0.60 API, T39	113	0	3.000	.035	.08	.02	3.000	.035	.08	.02
Cal. 0.60, Inc, T36E2	163	0	1.050	.009	.04	.00	2.000	.057	.11	.03
20mm, Inc, M96	142	0	1.000	.010	.04	.00	3.000	.019	.04	.00
20mm, HEI, M97	176	0	3.090	.018	.08	.00	4.050	.024	.06	.03
3cm, HE, Mk108, (German)	60	4	9.565	.094	.20	.03	14.273	.129	.24	.05
37mm, HE, M54	13	0	.790	.086	.40	.00	2.390	.252	.56	.05
75mm, HE, M48	11	7	8.200	.579	.86	.25	8.580	.604	.88	.26

*Weighted by relative areas of zones $P_{A_s} = \sum W_i \frac{A_i}{N_i}$

W_i = relative area of each zone
A_i = number of "A" kills in zone due to structures
N_i = number of impacts in each zone
$i = F_1, F_2, F_3, \ldots W_1, W_2, \ldots$(e.g.) all zones with recorded impacts

TABLE F5

Hits on Pilot Personnel in B-25 Structures Firings

Ammunition	Total number of hits on those zones yielding pilot damage	Number of Hits on Near Pilot	Relative Number of Hits on Near Pilot	Number of Hits on Far Pilot	Relative Number of Hits on Far Pilot
Cal. 0.50, API-T, M20	85	6	.071	1	.012
Cal. 0.60, API, T39	63	3	.048	1	.016
Cal. 0.60, Inc, T36E2	57	3	.053	1	.018
20mm, Inc. M96	34	3	.088	1	.029
20mm, HEI, M97	37	1	.027	0	.000
3cm, (German) MK108	11	1	.091	1	.091
37mm, HE, M54	13	1	.077	1	.077

TABLE F

STRUCTURE COMPONENT DAMAGE

[illegible]

TABLE F (cont'd)

STRUCTURE COMPONENT DAMAGE

Component		Size	P_k	[illegible]
C4	Aileron and hinge brackets	1	.000	[illegible]
C5	Aileron cables and bell crank	2	.000	[illegible]
C6	Aileron tab and tab cables	1	.000	[illegible]
C8	Rudder and hinge brackets	9	.102	[illegible]
C9	Rudder cables and bell crank	0	.020	[illegible]
C9	Rudder tab and tab cables	7	.014	[illegible]
C10	Wing flaps and actuating mechanism	4	.014	[illegible]
L1	[illegible]	0	.014	[illegible]
L2	[illegible]	1	.170	[illegible]
L3	Hydraulic main system	0	.000	[illegible]
L4	Hydraulic emergency power system	2	.000	[illegible]
L5	Hydraulic landing gear emergency lowering system	0	.004	[illegible]
L6	[illegible] brake system	0	.000	[illegible]
L7	Hydraulic fluid reservoir	1	.002	[illegible]
[illegible]	Wing skin, stringers [illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Wing spars, [illegible] web and landing gear beam	27	[illegible]	[illegible]
[illegible]	Horizontal stabilizer skin, stringers, [illegible]	[illegible]	[illegible]	[illegible]
[illegible]	Horizontal stabilizer spars	[illegible]	[illegible]	[illegible]
[illegible]	Vertical stabilizer skin, stringers, [illegible]	[illegible]	.051	[illegible]
[illegible]	Vertical stabilizer spars	0	[illegible]	[illegible]
[illegible]	Fuselage skin, stringers, frames, bulkheads and stiffeners	[illegible]	[illegible]	[illegible]
[illegible]	Fuselage longerons, [illegible] rails	[illegible]	.012	[illegible]
[illegible]	[illegible] and windshields	10	[illegible]	[illegible]

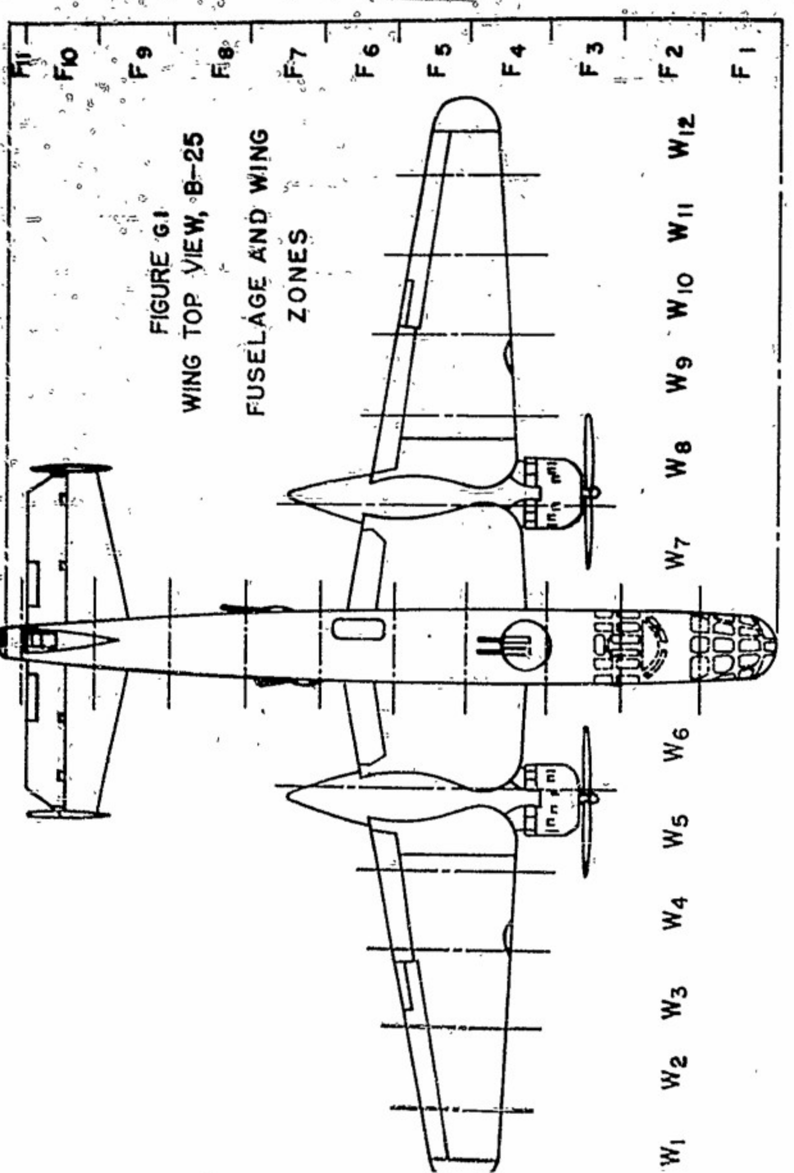
TABLE F7

Hits on Components per Thousand Hits on B-25 Rear Above Θ = 20°, Φ = 13°

Components	.50 API-TM20 N = 429	.60 API,T39 N = 342	.60 Inc.T36 N = 245	20mm HEI M97 N = 232	20mm Inc.M96 N = 169	3cm Mk108 N = 41	37mm HEM54 N = 57	75mm HEM48 N = 16	105mm HEM1 N = 6
A 1 = bombs, shackles, and bomb-racks	12	15	4	26	18	-	53	125	333
2 = bomb release wiring in bomb-bay	2	3	-	4	8	73	53	-	-
3 = bombardier bomb release panel & wiring in bombardier compartment	-	-	4	-	-	-	18	-	-
C 4 = pilot bomb release panel, & wiring in pilot compartment	2	-	-	-	-	-	-	-	-
5 = nose guns	-	-	-	-	6	-	18	-	-
6 = blister guns	-	3	-	4	-	-	-	62	-
7 = upper turret guns	5	6	8	4	6	-	18	62	-
8 = waist guns	2	15	8	-	12	-	18	-	-
9 = tail guns	2	6	4	-	6	24	18	-	-
10 = steel/armor plate	44	50	90	4	65	-	70	62	-
11 = aluminum alloy deflection plate, burst plate, flak plate	23	15	45	4	12	-	53	62	-
P 1 = pilot	14	9	4	-	24	24	-	62	-
2 = co-pilot	2	6	12	4	6	24	-	62	-
3 = bombardier	-	6	8	9	18	-	53	-	-
4 = upper turret gunner	9	3	8	9	12	-	53	62	-
5 = waist gunner	14	12	8	17	6	-	18	62	-
6 = tail gunner	9	9	-	22	6	-	35	62	-
F 1 = fuel pressure lines (exclusive of cabin heater fuel lines)	-	-	4	9	6	49	-	62	333
2 = front main cell	19	44	24	39	53	49	35	312	333
3 = rear main cell	28	53	57	47	53	73	88	250	333
F 4 = front auxiliary cell	7	3	16	26	6	-	-	-	-
5 = rear auxiliary cell	16	15	16	13	12	-	35		333
6 = outboard auxiliary cell	12	29	8	26	6	24	88	62	-
O 1 = oil cell, and oil sump	-	6	-	4	6	-	-	62	-
2 = oil coolers, & intake air-ducts	12	12	24	22	24	49	18	125	-
3 = oil pressure lines	2	3	-	13	6	49	70	125	-
C 1 = elevator & hinge brackets	28	23	53	47	83	146	140	-	167
2 = elevator cables and bellcranks	5	-	-	13	6	-	18	125	333
3 = elevator tab & tab cables	7	3	9	22	6	24	53	188	-
4 = aileron & hinge brackets	2	20	24	47	53	73	53	62	333
5 = aileron cables and bellcranks	1	23	20	39	12	49	123	125	187
6 = aileron tab & tab cables	2	6	12	13	-	73	105	62	-
7 = rudder & hinge brackets	21	44	41	47	30	98	70	-	-
8 = rudder cables and bellcranks	12	9	8	30	24	73	53	125	167
9 = rudder tab & tab cables	15	15	16	34	6	49	53	125	-
10 = wing flaps & actuating mechanism	14	76	24	91	65	98	140	250	-
L 1 = nose tire, wheel actuating mechanism	-	-	-	-	-	-	-	-	-
2 = main tire, wheel, actuating mechanism	14	18	12	34	18	98	105	125	333
3 = hydraulic main system	9	12	4	26	18	-	-	62	-
4 = hydraulic emergency power system	-	-	-	-	-	-	-	-	-
5 = hydraulic landing gear emergency lowering system	-	-	-	9	-	-	-	-	-
L 6 = air blast emergency brake system	-	-	-	-	-	-	-	-	-
7 = hydraulic fluid reservoir	2	3	-	-	12	-	-	-	[illegible]
S 1 = wing skin, stringers, ribs and engine nacelles	205	310	224	652	447	501	526	750	667
2 = wing spars; fuel cell web and landing gear beam	86	247	171	284	226	265	421	662	667
3 = horizontal stabilizer skin stringers, and ribs	47	41	57	65	83	73	123	188	167
4 = horizontal stabilizer spars	40	50	49	30	30	146	105	164	167
5 = vertical stabilizer skin stringers, and ribs	51	32	33	69	71	122	70		
6 = vertical stabilizer spars	21	32	27	52	41	122	53		
7 = fuselage skin, stringers, frames, bulkheads, and stiffeners	226	166	[illegible]	237	249	341	404	500	500
8 = fuselage longerons, and rails	12	18	29	62	53	73	175	375	500
9 = safety-glass and plexiglas	33	47	73	18	59	98	158	250	667

Appendix G

ILLUSTRATIONS OF STRUCTURAL CHARACTERISTICS



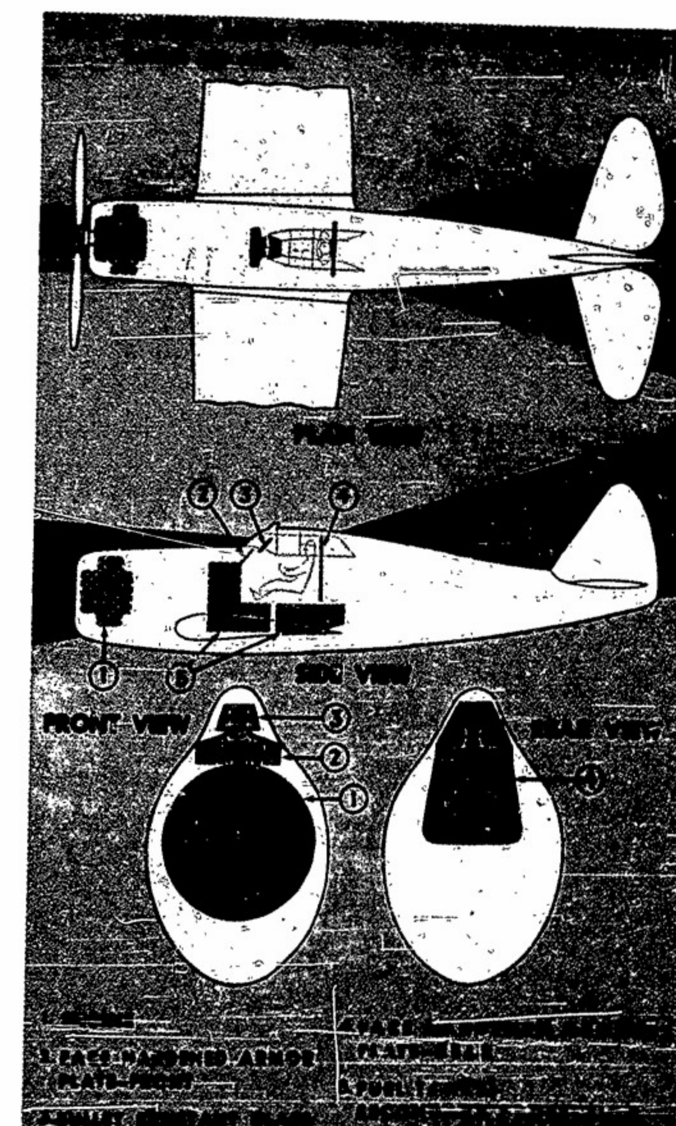


Figure G2 - Angles of Personnel Protection P-47.

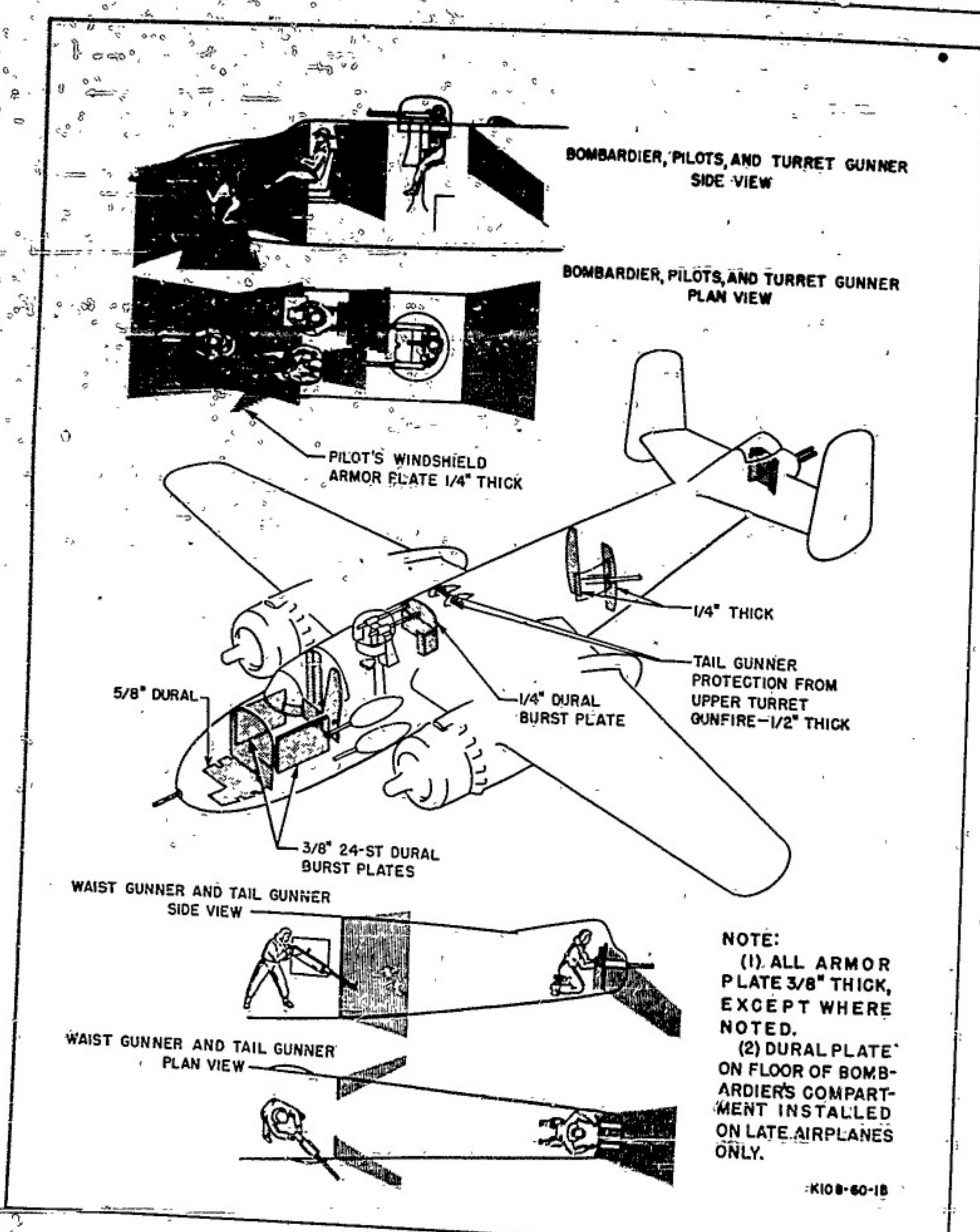
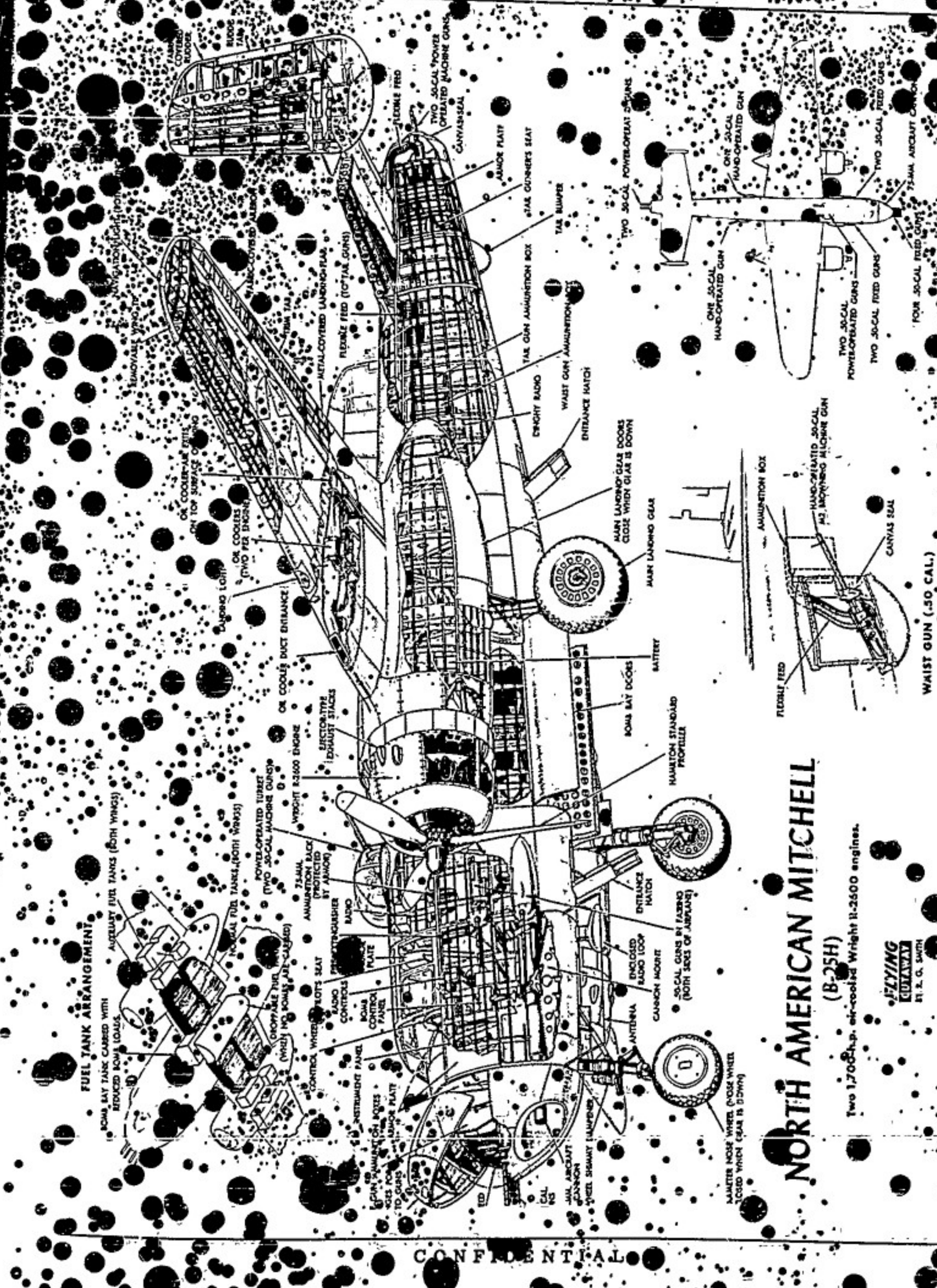


Figure G3 - Armor Protection.



Appendix H

CALCULATION OF RELATIVE PRESENTED AREAS

A view of the P-47 model in the aspect employed in the vulnerability computations of the body of this report is shown in Fig. H1. Figures H2, H3, and H4 show three aspects of the B-25 model. The areas presented to impact by the various components are tabulated in Table H1. Fig. H2 shows the aspect used in the overall vulnerability computations in the body of this report.

The presented area for the B-25 from the rear and above presented in Table H1 considers only the first surface hit by the projectile. If no masking of these areas by other surfaces, such as tail surfaces, is assumed, a larger overall value (298 Sq. ft.) is obtained.

Figure H1 - Model Photograph For Getting Projected Areas Of The P-47, Front and Below, $\theta = 20°$, $\phi = 20°$.

Figure H2 - Model Photograph For Getting Projected Areas Of The B-25, Rear and Above, $\theta = 20°$, $\phi = 13°$.

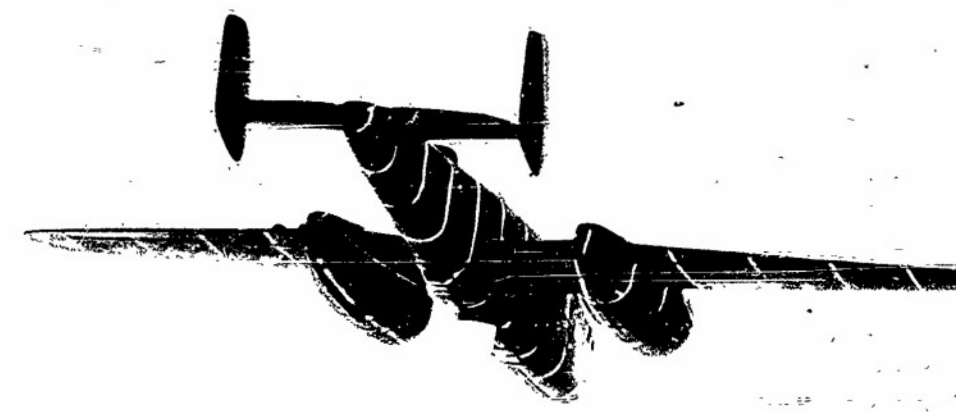


Figure H3 - Model Photograph For Getting Projected Areas Of The B-25, Rear and Below, $\theta = 20°$, $\phi = 13°$.

Figure H4 - Model Photograph For Getting Projected Areas Of The B-25, Front and Below, $\theta = 20°$, $\phi = 13°$.

TABLE H1
B-25 Projected Areas

Line of Fire / ZONE	Rear, θ=20°, Sq. ft.	Above Ø=13° Relative Area	Rear, θ=20°, Sq. ft.	Below Ø=-13° Relative Area	Front, θ=0°, Sq. ft.	Level Ø=0° Relative Area	Front, θ=20°, Sq. ft.	Above Ø=-13° Relative Area	Front, θ=20°, Sq. ft.	Below Ø = 13° Relative Area
F 1	1	.004	3	.007	19	.111	26	.085	0	.040
F 2	5	.020	9	.030	19	.110	26	.085	22	.088
F 3	7	.027	9	.026	0	.000	19	.063	22	.088
F 4	6	.023	9	.030	0	.000	16	.054	17	.069
F 5	3	.012	12	.036	0	.000	10	.034	12	.047
F 6	10	.039	15	.044	0	.000	8	.026	7	.029
F 7	11	.043	18	.054	0	.000	12	.040	6	.022
F 8	9	.035	15	.044	0	.000	9	.028	6	.022
F 9	8	.031	12	.036	0	.000	3	.011	6	.022
F 10	5	.020	9	.026	0	.000	1	.002	5	.021
F 11	5	.020	3	.010	0	.000	0	.000	1	.004
W 1	6	.023	3	.008	3	.016	3	.009	6	.022
W 2	9	.035	5	.015	6	.033	6	.020	6	.023
W 3	11	.043	8	.023	6	.036	8	.026	8	.031
W 4	14	.055	8	.023	9	.049	9	.028	10	.038
W 5	19	.074	14	.040	20	.113	24	.080	12	.048
W 6	14	.055	35	.106	16	.094	24	.080	13	.054
W 7	13	.051	16	.049	18	.103	13	.043	11	.043
W 8	15	.058	45	.134	23	.133	4	.014	11	.046
W 9	10	.039	11	.034	9	.049	8	.026	7	.027
W 10	7	.027	9	.030	8	.046	9	.031	6	.022
W 11	7	.027	8	.023	5	.027	5	.014	4	.017
W 12	4	.016	4	.013	3	.016	6	.020	1	.006
Far HT	14	.055	16	.049	2	.013	13	.043	2	.008
VT	15	.056	15	.044	3	.021	12	.040	2	.008
Near HT	14	.055	9	.030	2	.013	15	.048	9	.036
VT	15	.056	13	.038	3	.021	10	.034	17	.068
Total	257	1.000	333	1.000	175	1.000	299	1.000	231	1.000
Near nacelle	9	.035	40	.116	20	.114	19	.063	28	.113
Far nacelle	9	.035	40	.116	19	.108	20	.064	19	.074
Near main fuel tank	20	.078	8	.023	6	.034	11	.037	7	.028
Far main fuel tank	18	.071	14	.040	6	.034	3	.011	0	.000
Near aux. fuel tank	16	.063	5	.015	4	.023	10	.034	5	.021
Far aux. fuel tank	15	.060	13	.038	4	.023	9	.028	0	.000

Appendix J

COMMENTS ON THE LIMITATIONS OF ATTACKS ON BOMBERS BY FIXED GUN FIGHTERS

1. A simple example of the relationship between type of armament installation and tactics is the case of the fixed gun fighter. In order to keep the bomber continuously under fire, the fighter is constrained to fly a pursuit-type course. Such a course has the characteristic that the radius of curvature of the path which the fighter must fly becomes smaller and smaller, in general, as the fighter nears the bomber. There is a region broadside of the bomber within which the accelerations required of the fighter on a gun bearing course are so great that the bomber cannot be kept under continuous fire in this region.

2. Acceleration Limits on the Fighter:

a. A fixed gun fighter attacking a bomber must fly what is termed a pursuit course. Typical shape of a pursuit course relative to the bomber is shown in Figure J1. As the range shortens, the curvature of the fighter's path increases, in general, the lift force required to hold the fighter on course increases and finally a value of radial acceleration is reached which exceeds either the pilot's ability to remain conscious, or the fighter's ability to obtain the required lift force from its wings. Tests of a P-47 fighter attacking a B-29 bomber in New Mexico indicated a maximum acceleration attained by attacking fighters of 3.5g at 26000 ft altitude and 2.8g at 32000 altitude.

b. To estimate the limits imposed by this acceleration maximum, the following procedure is carried out. Conditions are idealized to the assumptions that the bomber flies an unaccelerated course, the fighter flies at constant speed, the action takes place in a plane, the fighter's rounds travel at constant speed along straight line trajectories, and the fighter flies in the direction in which its guns point, with no mush, skid, or slip. Then using the notation of Figure J2, the angular velocity ω_o of the fighter's line of sight is

$$\omega_o = (v_b \sin \alpha_o - v_f \sin \lambda)/r \qquad (1)$$

where r is present slant range, α_o is angle off the bomber's nose, v_f is fighter's air speed, v_b is bomber's air speed, and λ is lead angle.

If lead angle is continuously and correctly computed

$$\sin \lambda = v_b/v_a \quad \sin \alpha_o \qquad (2)$$

where v_a is average projectile air speed. If $\mathcal{V}_a$ is average projectile velocity relative to the fighter

$$v_a = v_f + \mathcal{V}_a \qquad (3)$$

For lead angles 15° and less it is satisfactory to write $\sin \lambda = \lambda$. Then

$$\lambda' = (v_b/v_a) \cos \alpha_o \, \omega_o \qquad (4)$$

The fighter's rate of turn is

$$\omega_p = \omega_o + \lambda' \qquad (5)$$

The radial acceleration produced by flight path curvature is

$$ng = v_f\,\omega_p \qquad (6)$$

where n is number of "g" acceleration. Then combining the above formulae

$$ng = (v_f v_b \sin\alpha_o / r)\ (1 - v_f/v_a)\left[1 + (v_b/v_a)\cos\alpha_o\right] \qquad (7)$$

c. From Eq. (7) the acceleration limits for a 1200 mph fighter attacking a 1000 mph bomber have been plotted for 3g, 4g, and 5g maximum acceleration in Figure J3. This figure shows limits when the fighter takes no lead. The shaded region is that in which the attack can be carried out.

d. When finite projectile velocity is considered, the limits shown in Figure J4 are obtained. The forbidden areas decrease in size. If the projectile had the same air speed as the fighter (air-air bombing), the fighter's path would be a straight line collision course and the acceleration limit would disappear.

e. The variation in size of the forbidden areas with aircraft speed is shown in Figures J5a, J5b, and J6.

3. **Lead Contours for Fighter:** The contours of constant fighter lead and time of flight are simple to construct from Eq. (2) for the idealized case of constant projectile velocity. They are shown in Figure J7. 10° lead was arbitrarily chosen. This is not a limit in the sense employed for the acceleration contours. However, errors in computing sights increase in general with the lead, as does the difficulty of lead computation. Also some sights have maximum lead limits in the neighbourhood of 10-15°.

Since projectiles do slow down rapidly at these high velocities, the curves of Figure J7 offer only a crude comparison, particularly beyond 1000 yards range.

4. **Combined Lead and Acceleration Limits:** The 5g acceleration contours and the 10° lead contours have been combined in Figure J8. It is indicated that at these high speeds continuous attack is possible only in [illegible] of the bomber.

5. **Bullet Slowdown:** In attacks in the bomber's tail cone the fighter is effectively firing into a very high head wind. It is informative to [illegible] range relative to the fighter which its rounds will attain. Suppose that the bomber and fighter are flying a distance r yards apart, and both at the same speed. Let t_f be bullet time of flight. Then a round fired by the fighter travels an air distance

$$P = r + v_b t_f \qquad (8)$$

to reach the bomber. If the round's velocity drops to v_b before it travels a distance P, it will not reach the bomber.

Using Sterne's formulae in somewhat different notation, the remaining velocity of the round relative to the air v_r is

$$v_r^{1/2} = u_o^{1/2} - aP \qquad (9)$$

where

$$u_o = v_f + v_o \qquad (10)$$

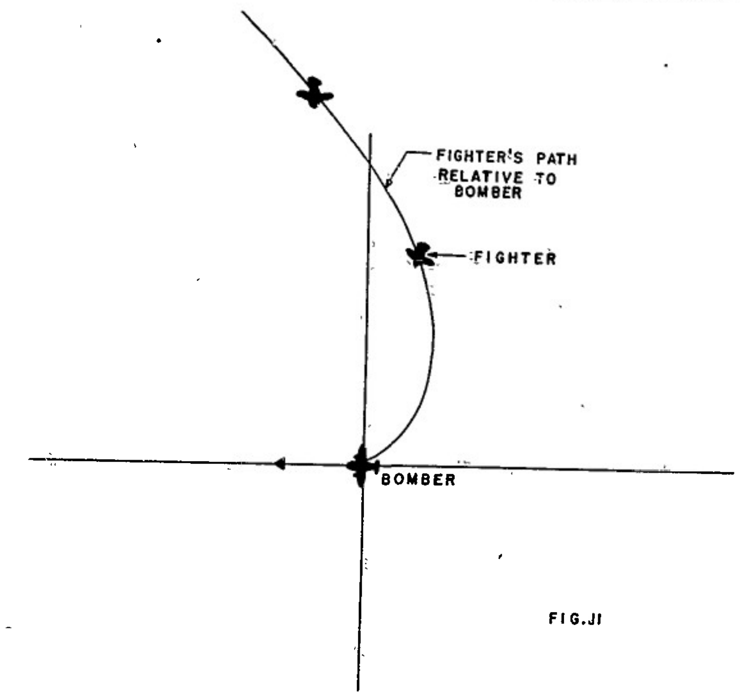


FIG. J1

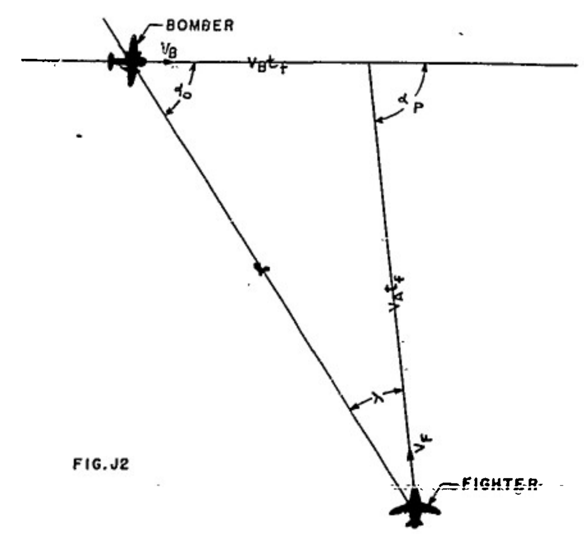


FIG. J2

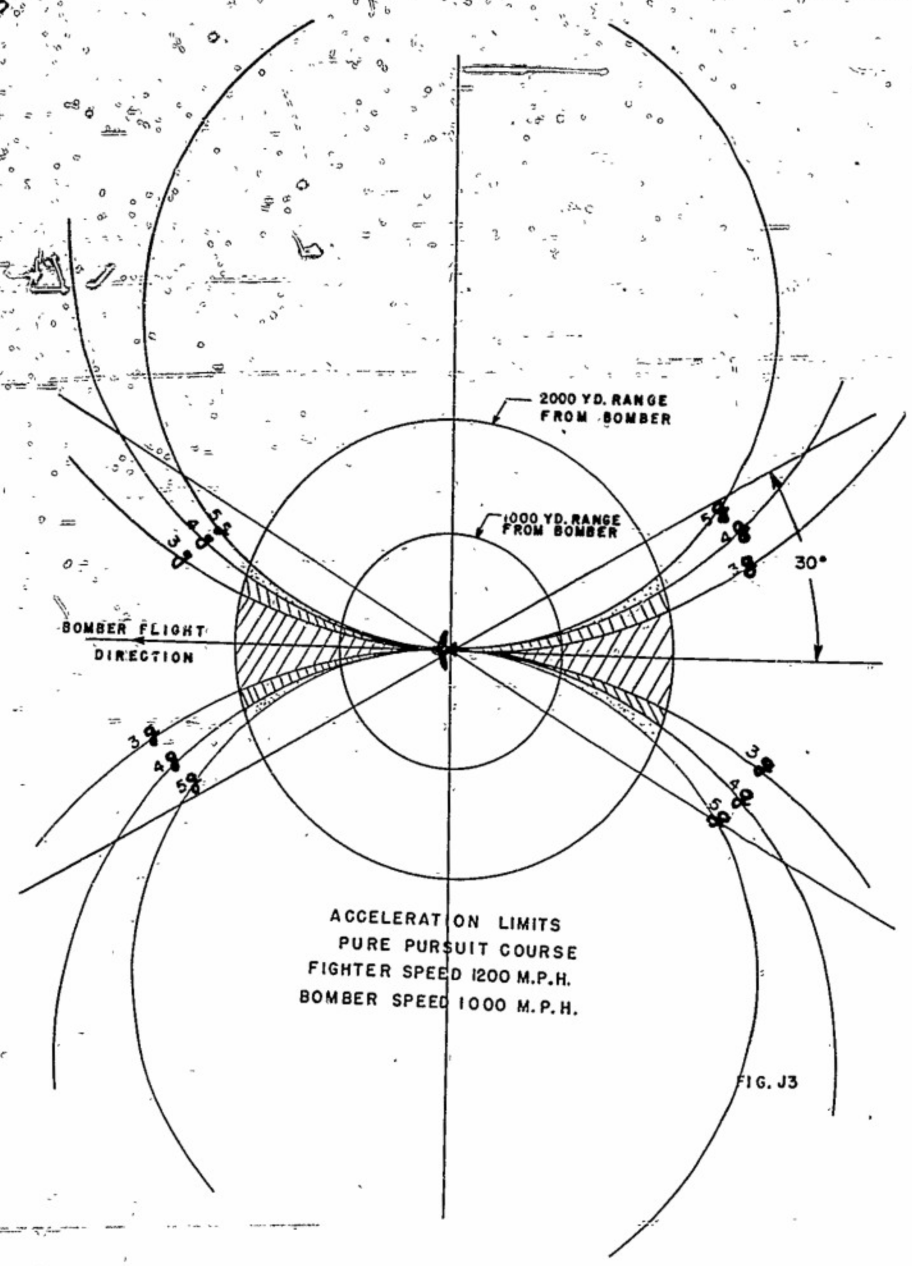


FIG. J3

and v_o is muzzle velocity. Coefficient "a" is

$$.00323 \quad \rho \; /c_5$$

where ρ is relative air density (1.00 at sea level) and c_5 is ballistic coefficient. Units are to be yards and seconds. Time of flight is given by

$$P/t_f = u_o - a u_o^{1/2} P \qquad (11)$$

and solving for the range r for which v_r drops to the speed of the launching fighter v_f (or the bomber v_b when $v_b = v_f$)

$$ar = u_o^{1/2} \left[1 - (v_f/u_o)^{1/2} \right]^2 \qquad (12)$$

Figure J9 shows ρr as a function of muzzle velocity and ballistic coefficient for fighter speed of 1000 mph. The curves may be read directly for sea level conditions. For any other altitude the ordinates should be divided by relative air density.

Considering the requirement of reaching a range 2000 yards relative to the fighter, Figure J9b shows the combination of muzzle velocity and ballistic coefficient required at sea level and at 16,500 ft. For a given muzzle velocity, of course, large guns project their rounds to greater ranges from the fighter than small guns.

6. The foregoing is a brief survey of some of the limitations on the attack of a bomber by a fixed gun fighter at subsonic and supersonic velocities. Many other questions which naturally arise concerning effect of aerodynamic characteristics of the fighter, probability of hitting, terminal effect of rounds, etc., can be answered in extended studies which it is hoped will be carried out as a part of the Optimum Caliber Program.

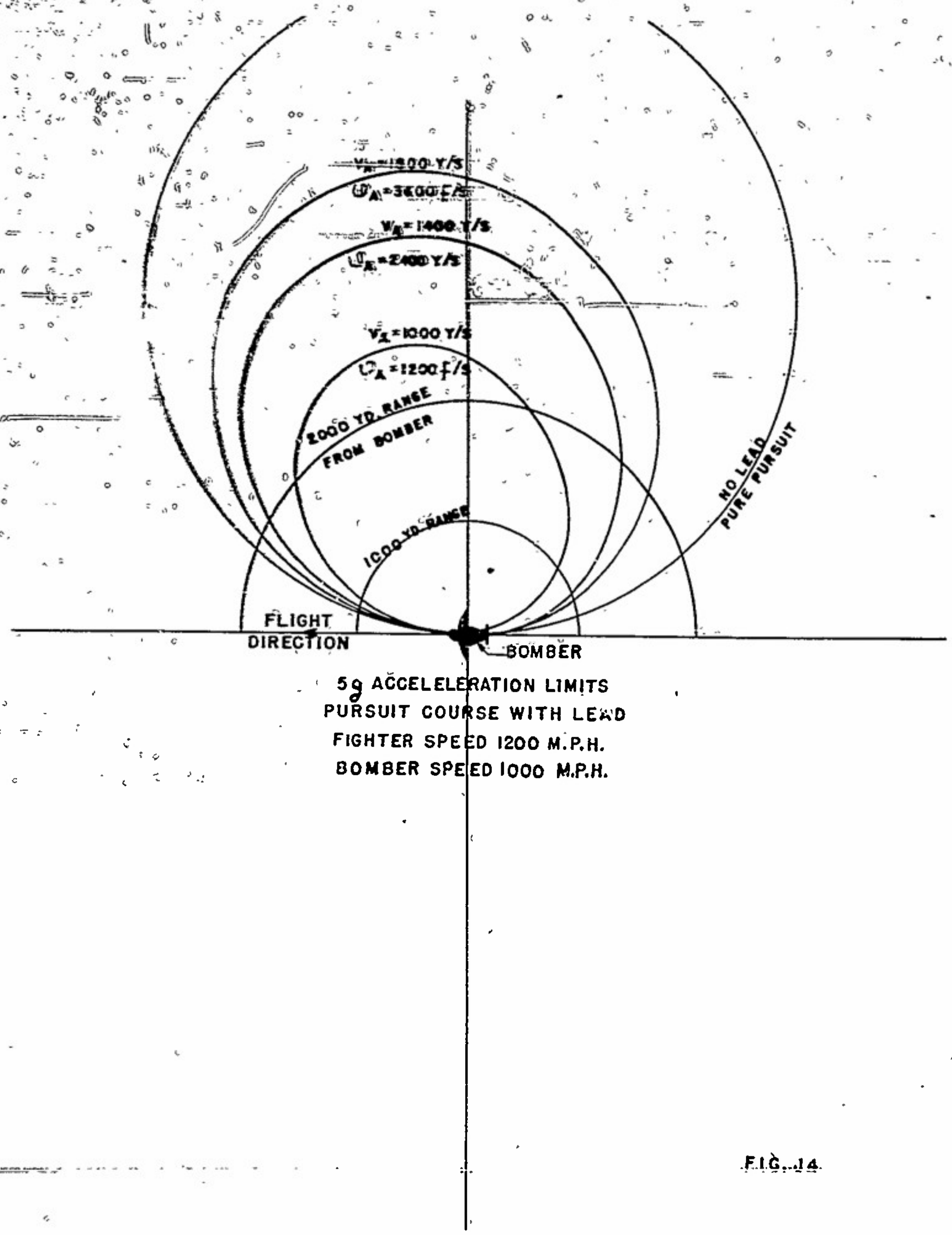
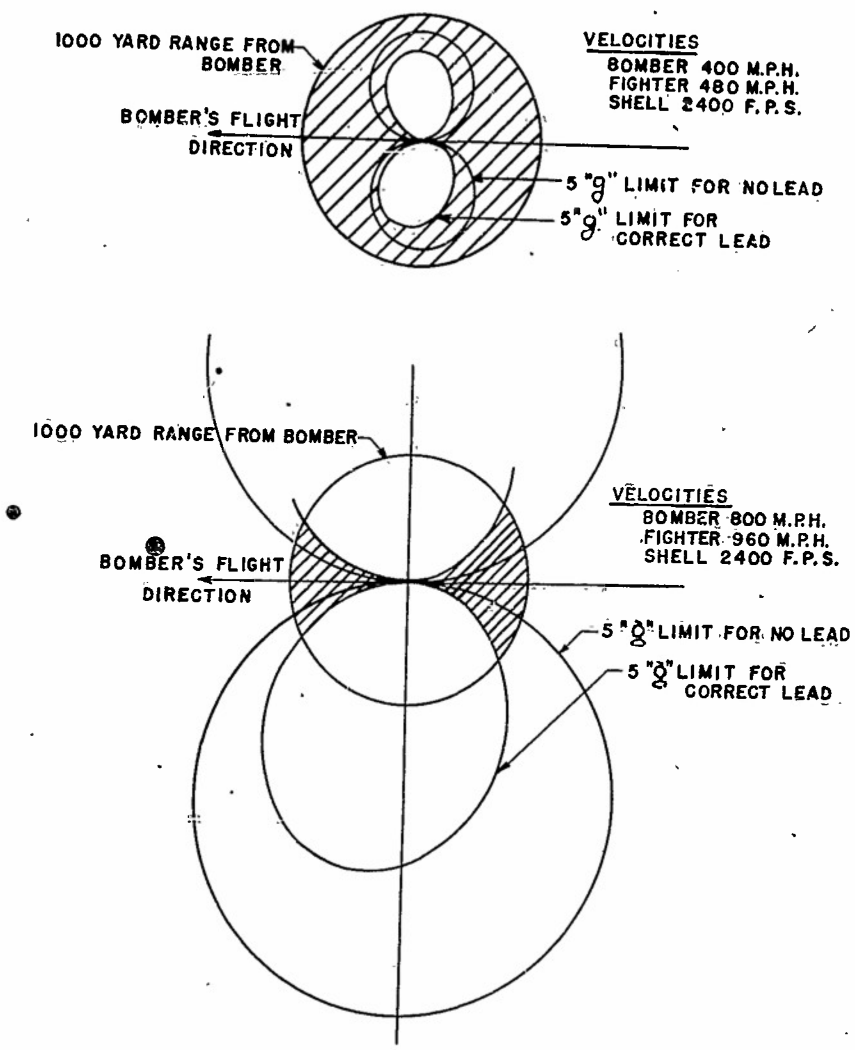


FIG. 14



FIGS. 15a, 15b

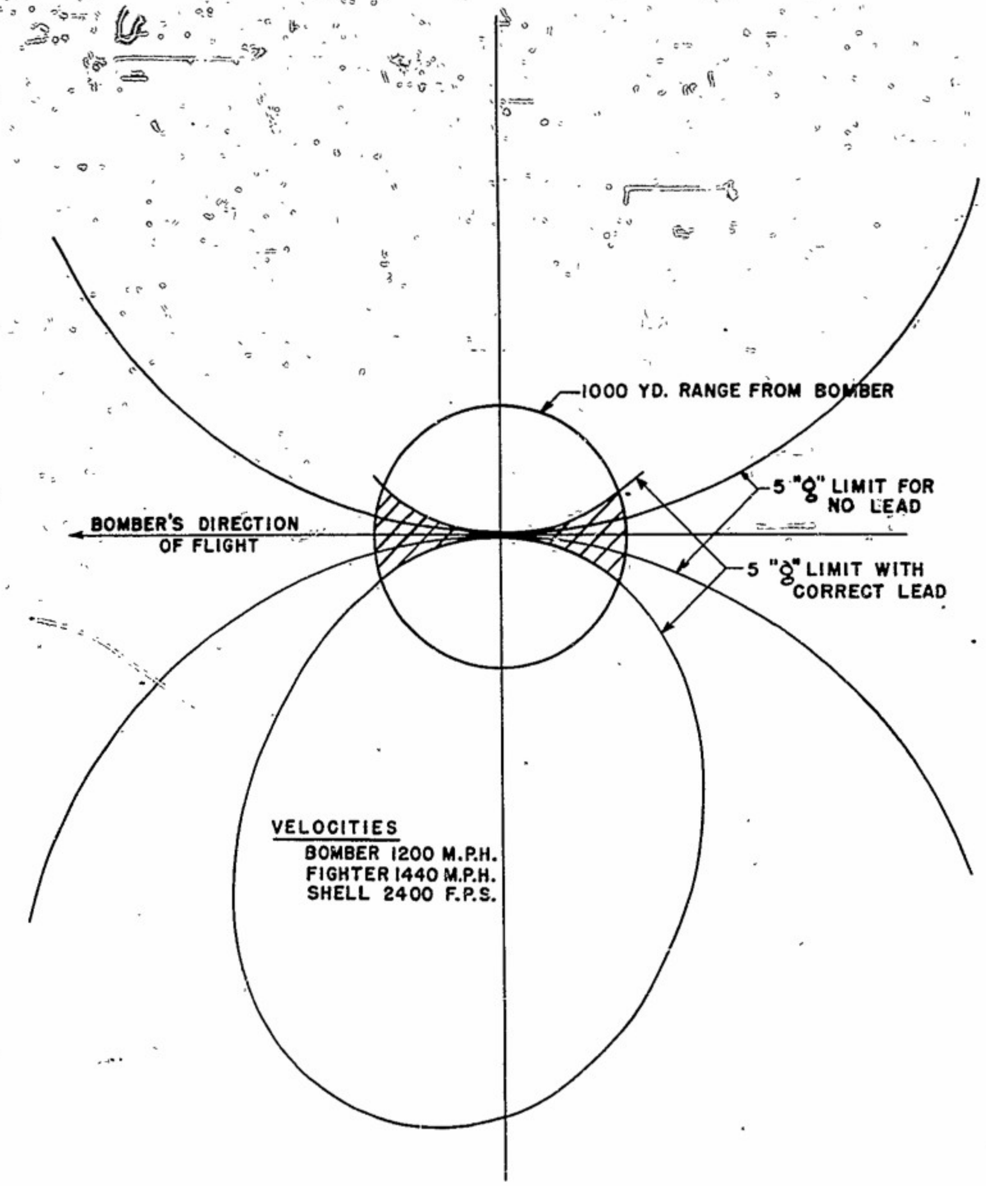

1000 YD. RANGE FROM BOMBER
5 "g" LIMIT FOR NO LEAD
BOMBER'S DIRECTION OF FLIGHT
5 "g" LIMIT WITH CORRECT LEAD
VELOCITIES
BOMBER 1200 M.P.H.
FIGHTER 1440 M.P.H.
SHELL 2400 F.P.S.

FIG. J6

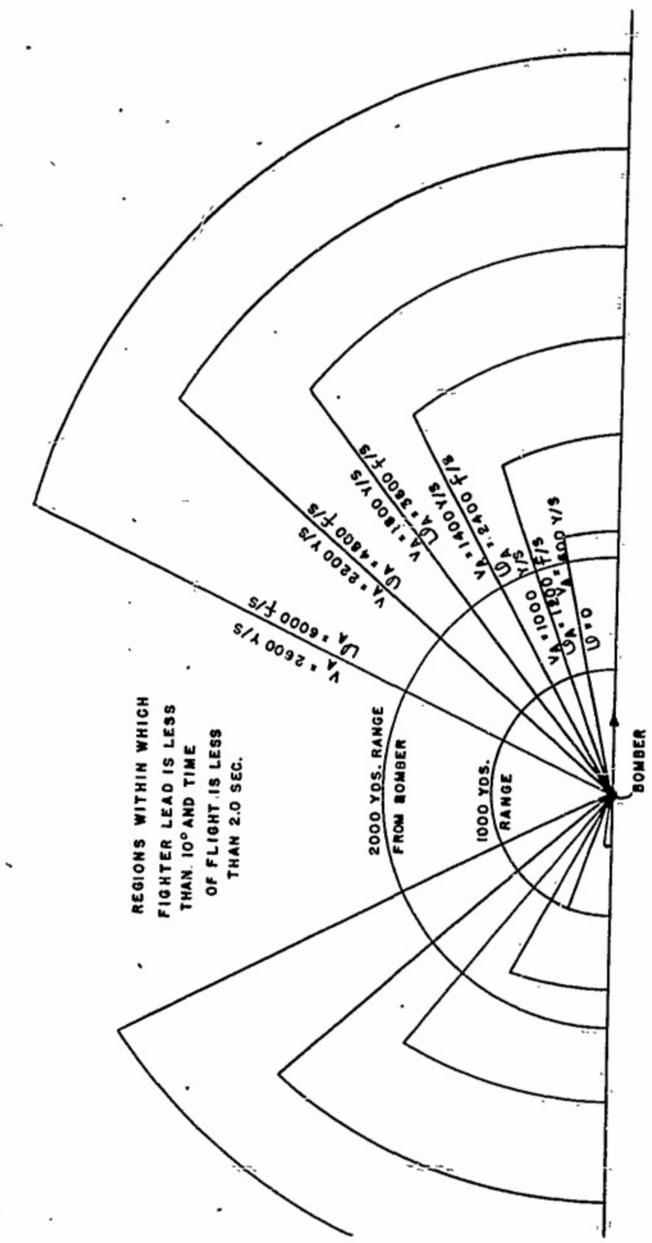
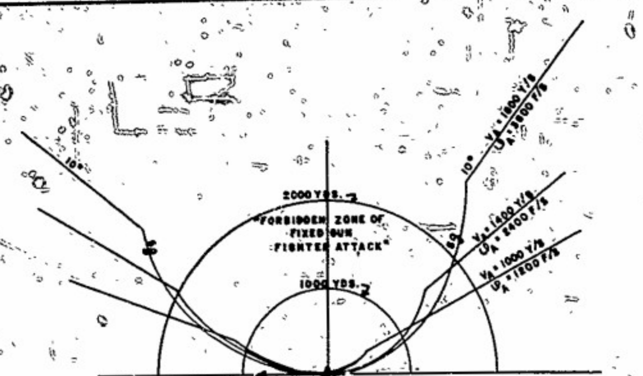
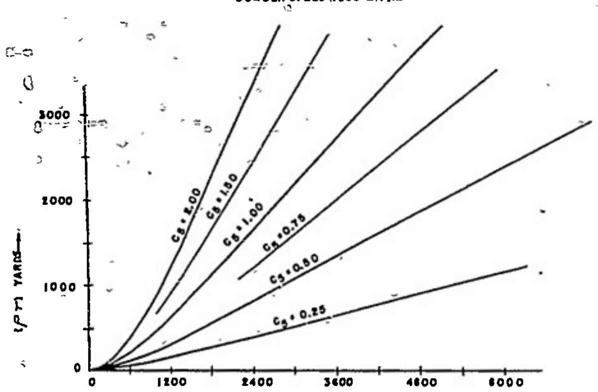

REGIONS WITHIN WHICH FIGHTER LEAD IS LESS THAN 10° AND TIME OF FLIGHT IS LESS THAN 2.0 SEC.
2000 YDS. RANGE FROM BOMBER
1000 YDS. RANGE
BOMBER

FIG. J7



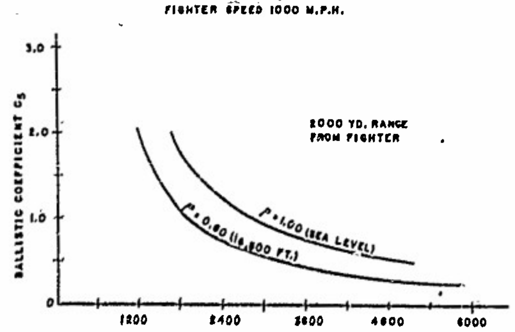
5G ACCELERATION PLUS 10° LEAD
LIMITS: PURSUIT COURSE WITH LEAD
FIGHTER SPEED 1200 M.P.H.
BOMBER SPEED 1000 M.P.H.

FIG. J8



FIGHTER SPEED 1000 M.P.H.

FIG. J9a



REQUIRED MUZZLE VELOCITY ~~AND BALLISTIC COEFFICIENT TO ATTAIN~~ SPECIFIED RANGES AHEAD OF FIXED GUN FIGHTER AT VARIOUS ALTITUDES

FIG. J9b

Appendix K

EXTERIOR BALLISTICS OF ROUNDS

1. The time of flight and remaining velocities of the rounds considered in the body of this report are presented in the following series of figures as functions of slant range measured from the muzzle of the moving gun. Target speed was taken as 450m.p.h. at a relative air density of 0.60. Computations are carried out for fire directly ahead and directly to the rear of the airplane carrying the gun. Where standard firing tables were available for the rounds they were used, otherwise the ballistic data was computed from the appropriate Siacci functions.

2. Figs. K1 to K4 show time of flight and Figs. K5 to K8 show remaining velocity vs. range.

3. The following table lists either the firing table used to obtain the plotted data or the ballistic coefficient used in its computation.

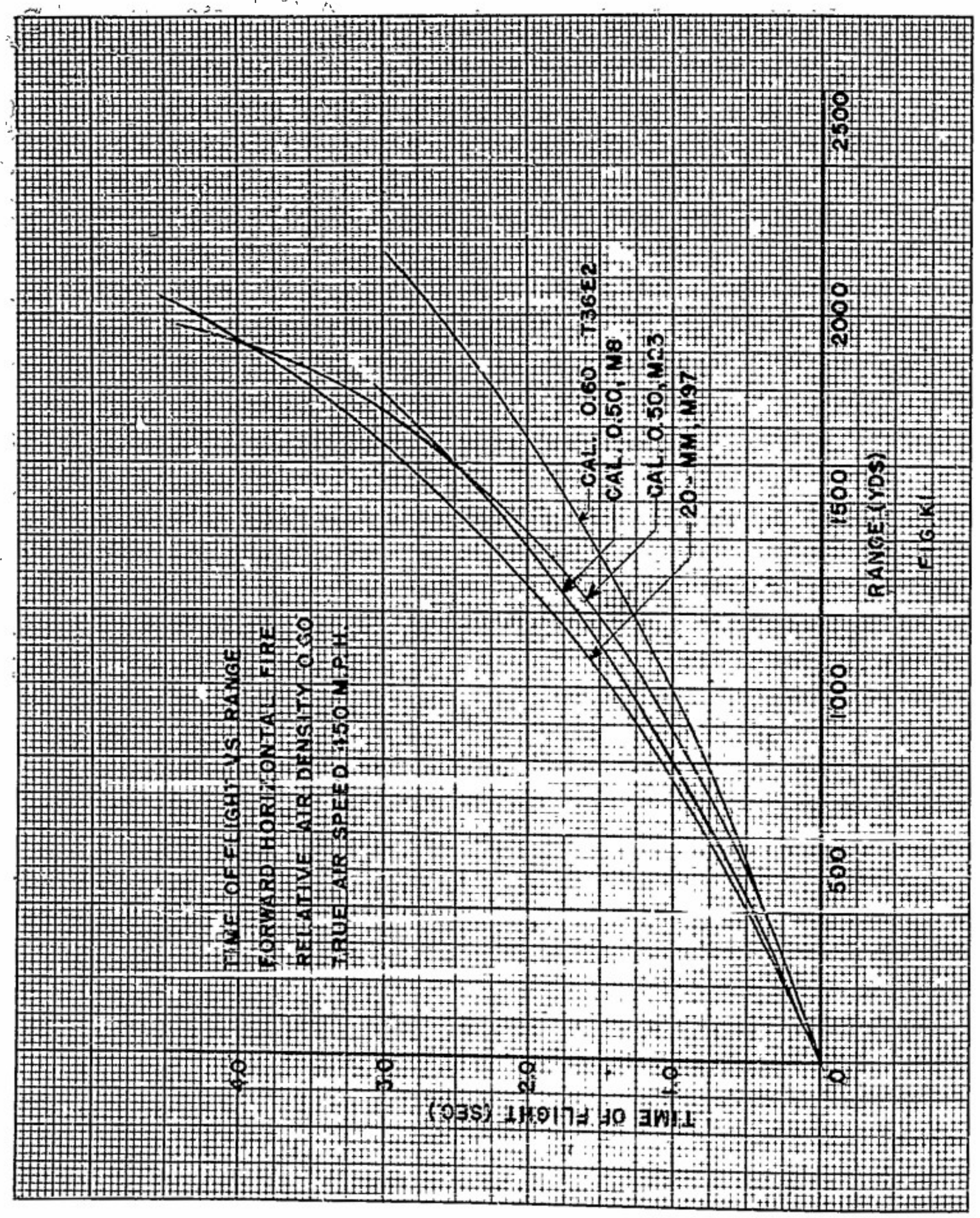

TIME OF FLIGHT VS. RANGE
FORWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 150 M.P.H.
CAL. 0.60, T36E2
CAL. 0.50, M8
CAL. 0.50, M23
20-MM, M97
0
500
1000
1500
2000
2500
RANGE (YDS)
0
1.0
2.0
3.0
4.0
TIME OF FLIGHT (SEC)

FIG. K1

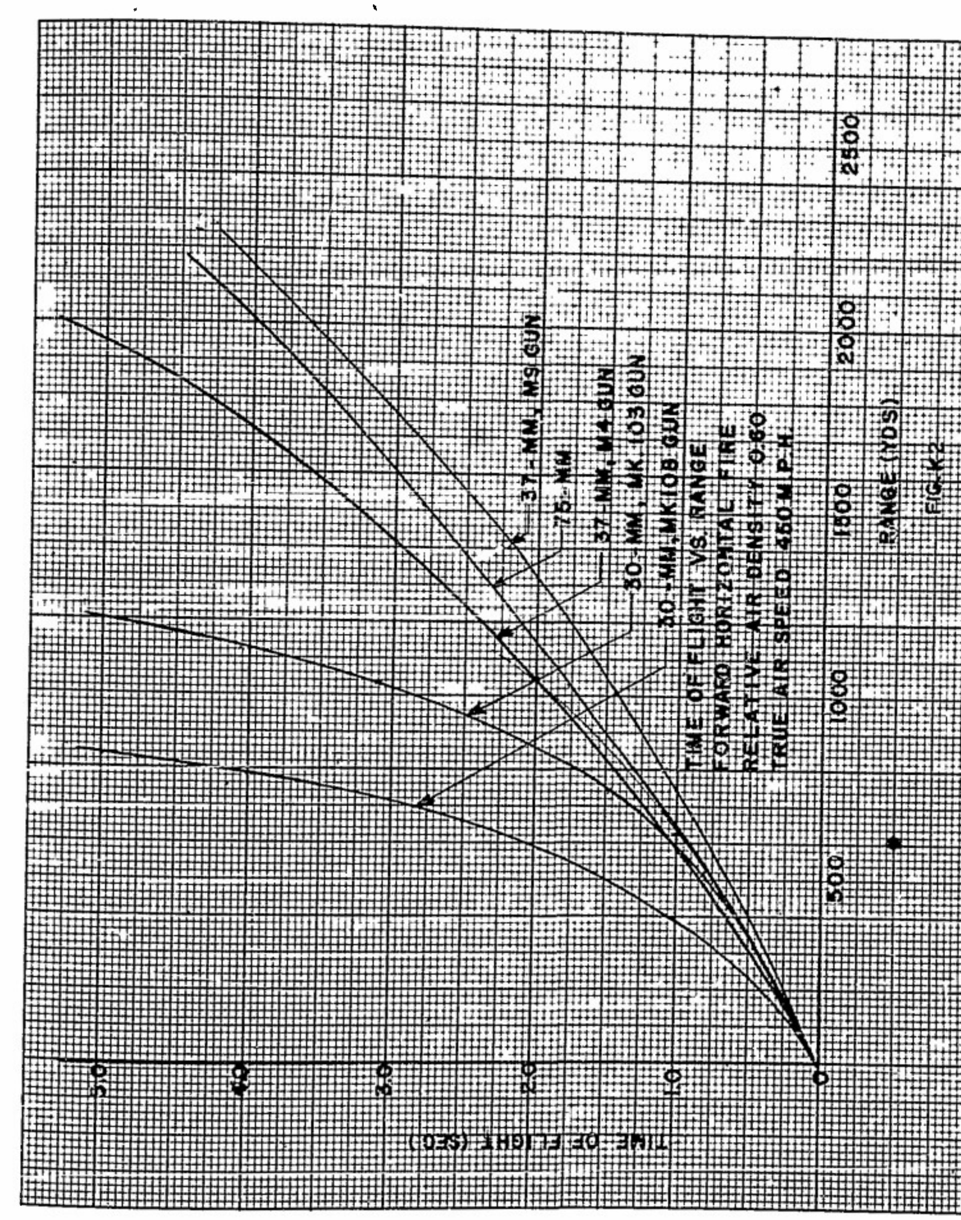
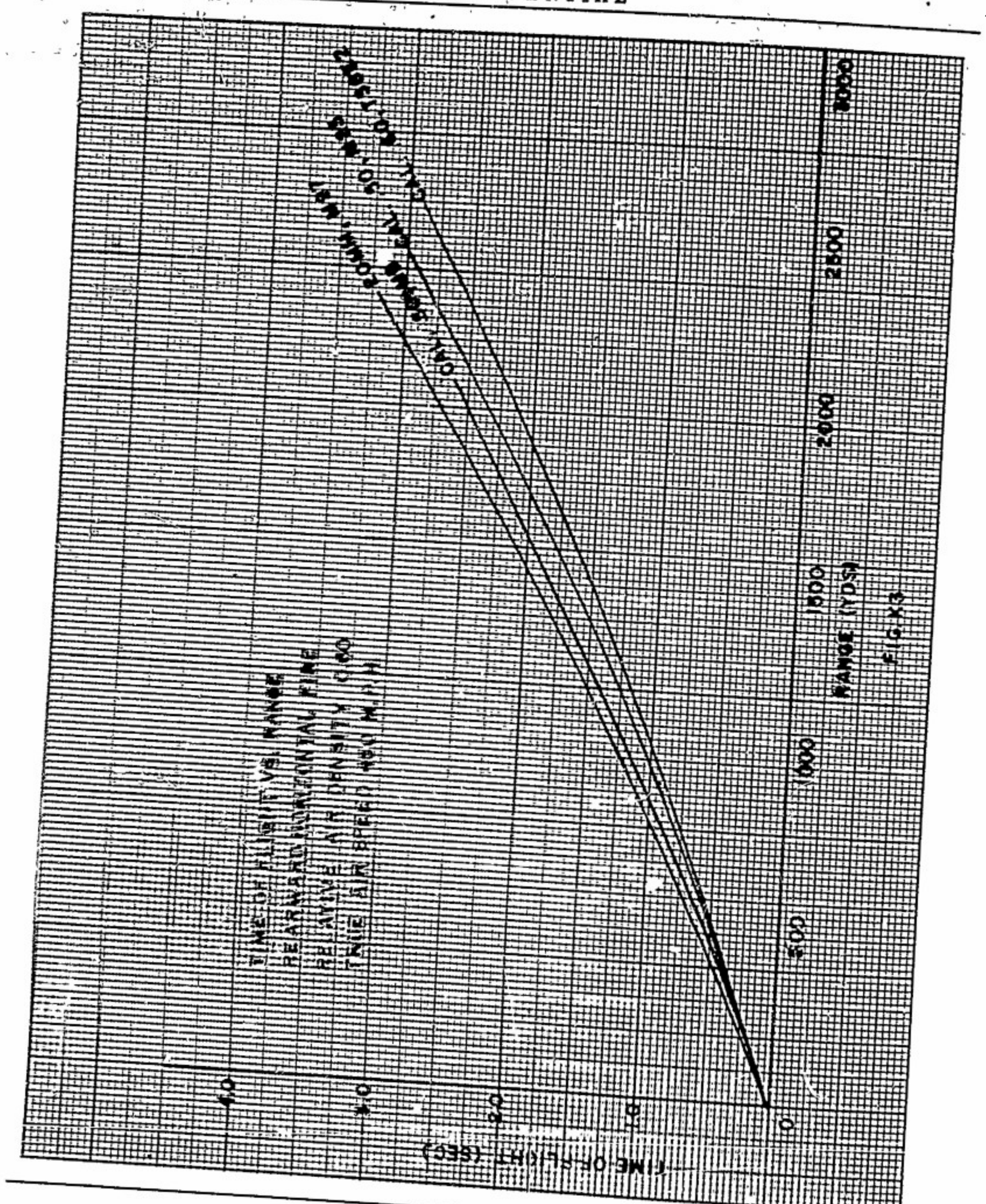
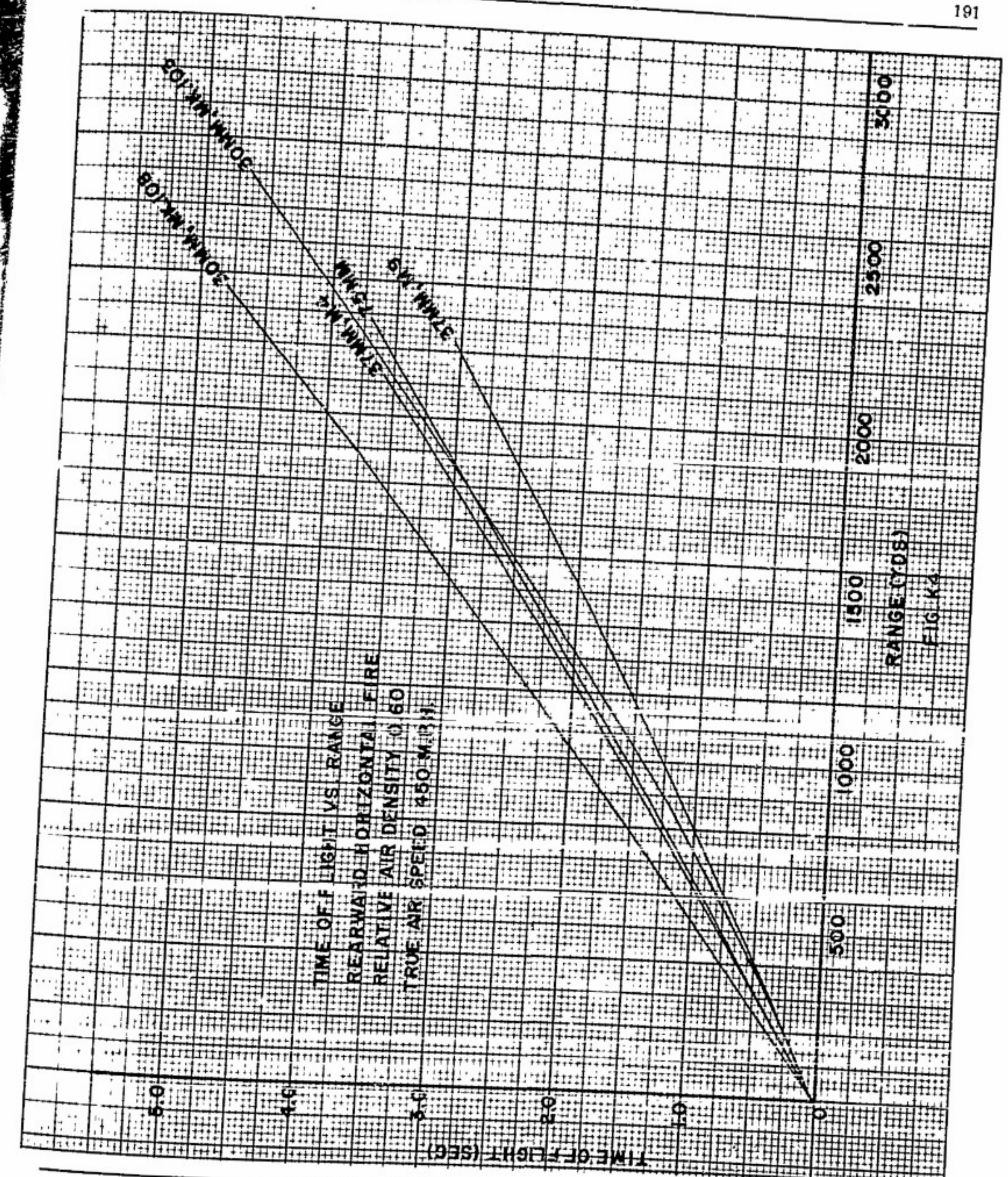

37-MM, M9 GUN
75-MM
37-MM, M4 GUN
30-MM, MK 103 GUN
30-MM, MK 108 GUN
TIME OF FLIGHT VS. RANGE
FORWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
0
500
1000
1500
2000
2500
RANGE (YDS)
0
1.0
2.0
3.0
4.0
5.0
TIME OF FLIGHT (SEC)

FIG. K2


TIME OF FLIGHT VS. RANGE
REARWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
RANGE (YDS)
TIME OF FLIGHT (SEC)
FIG. K3


30MM MK 103
30MM MK 108
37MM M9
37MM M4
TIME OF FLIGHT VS. RANGE
REARWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
RANGE (YDS)
TIME OF FLIGHT (SEC)
FIG. K4

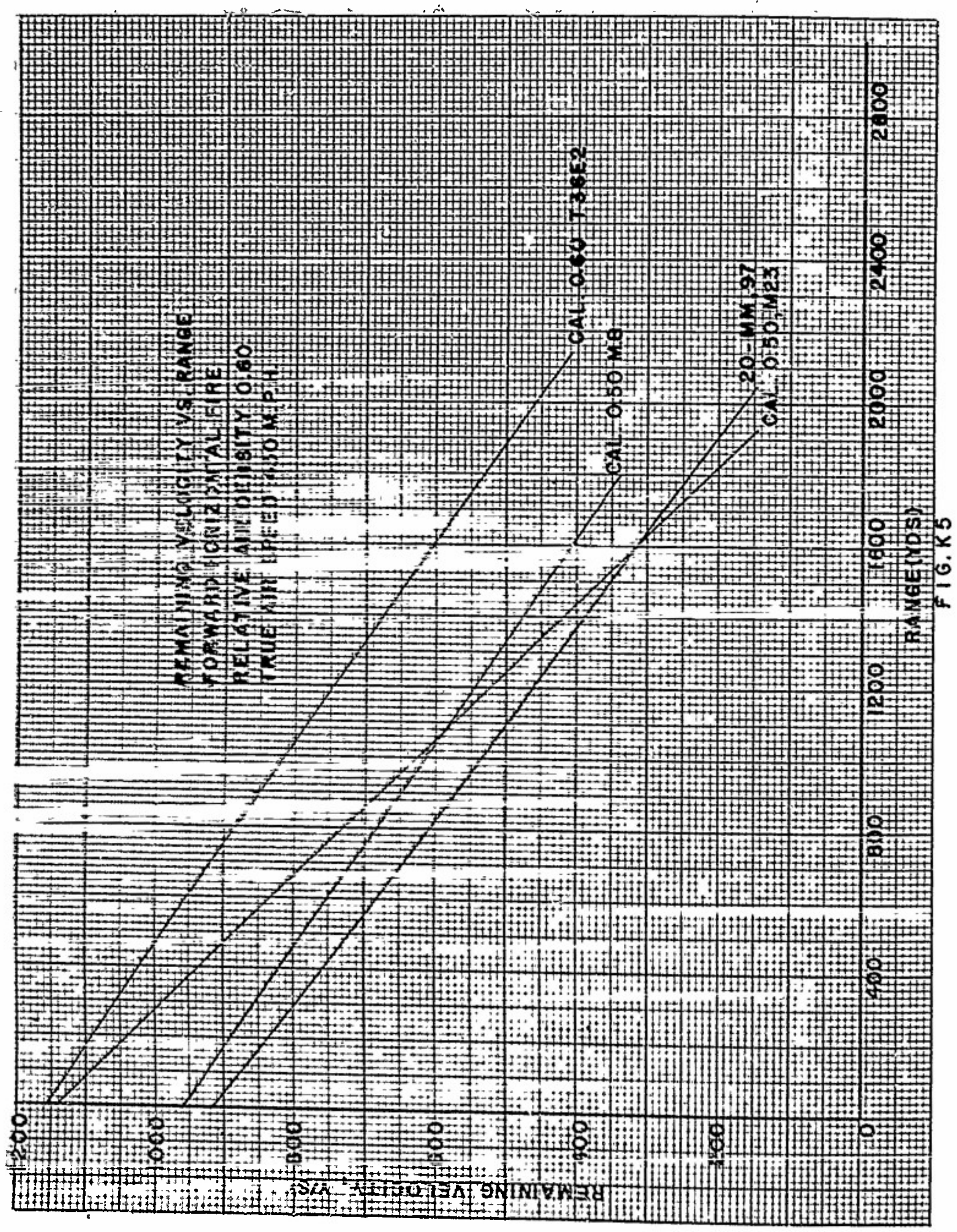

REMAINING VELOCITY VS RANGE
FORWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
CAL 0.60 T36E2
CAL 0.50 M8
20 MM 97
CAL 0.50 M23
RANGE (YDS)
REMAINING VELOCITY

FIG. K5

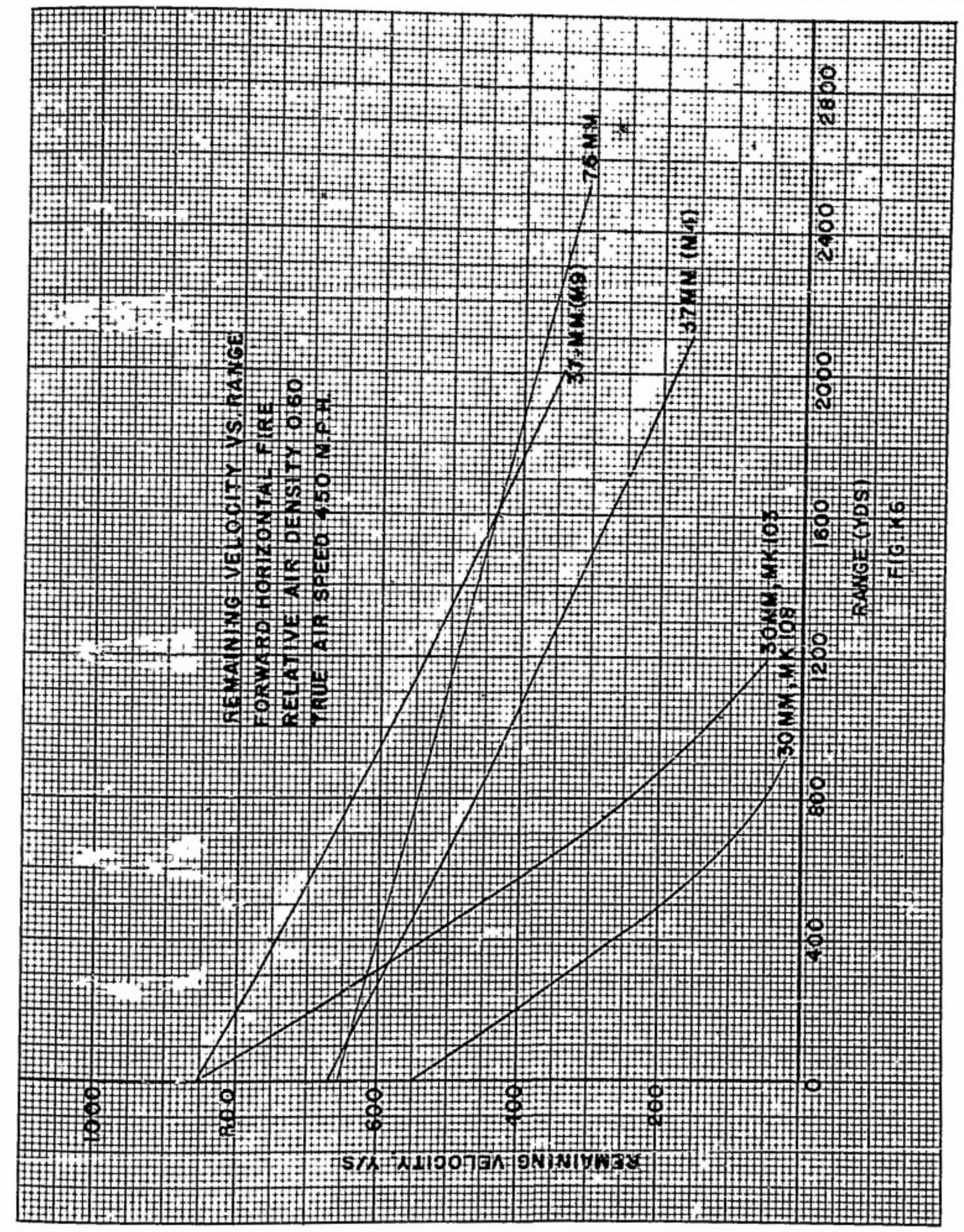

REMAINING VELOCITY VS. RANGE
FORWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
76 MM
37 MM (M9)
37 MM (M4)
30 MM MK 103
30 MM MK 108
RANGE (YDS)
REMAINING VELOCITY V/S

FIG. K6

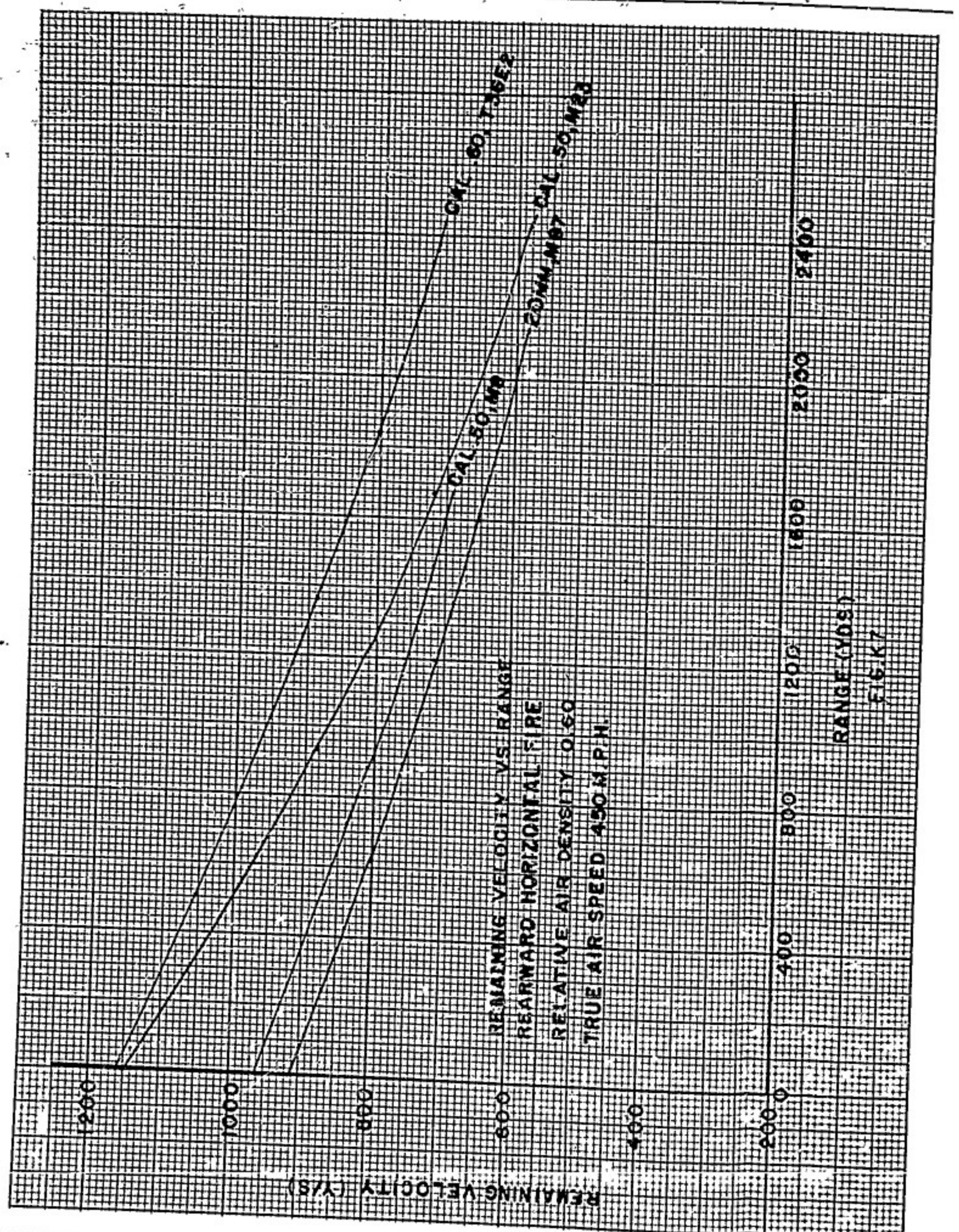

CAL .60, T36E2
CAL .50, M23
20MM, M97
CAL .50, M8
REMAINING VELOCITY VS. RANGE
REARWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
RANGE (YDS)
REMAINING VELOCITY (Y/S)

FIG. K7

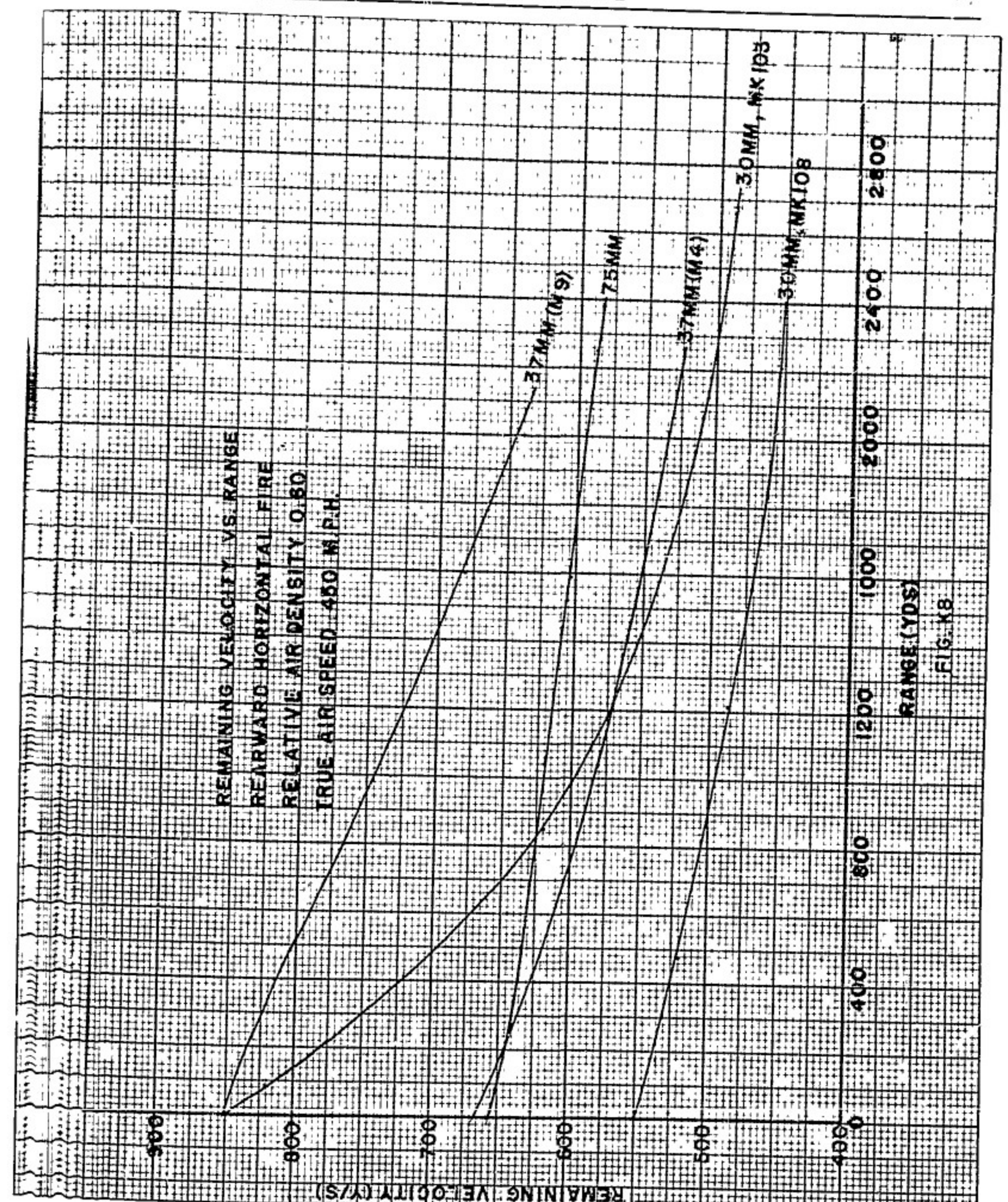

30MM, MK 103
30MM, MK 108
75MM
37MM (M4)
37MM (M9)
REMAINING VELOCITY VS. RANGE
REARWARD HORIZONTAL FIRE
RELATIVE AIR DENSITY 0.60
TRUE AIR SPEED 450 M.P.H.
RANGE (YDS)
REMAINING VELOCITY (Y/S)

FIG. K8

CAL. 0.50, M23	v = 3460 f/s	C_7 = .232
CAL. 0.50, M2, API, M8	v = 2870 f/s	FT 0.50 AC - Q - 1
CAL. 0.60, INC, T36, E2	v = 3480 f/s	C_8 = .360
20MM, M1, HE, M97	v = 2750 f/s	FT 20 AC - K -1
30MM, MARK 108	v = 1650 f/s	C_1 = .306
30MM, MARK 103	v = 2550 f/s	C_1 = .306
37MM, M4, HE, M54	v = 2000 f/s	FT 37 AC - AO - 1
37MM, M9, HE, M54	v = 2550 f/s	FT 37 AC - BF - 1
75MM, HE, M48	v = 1970 f/s	C_1 = 1.686